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On-Site Generation

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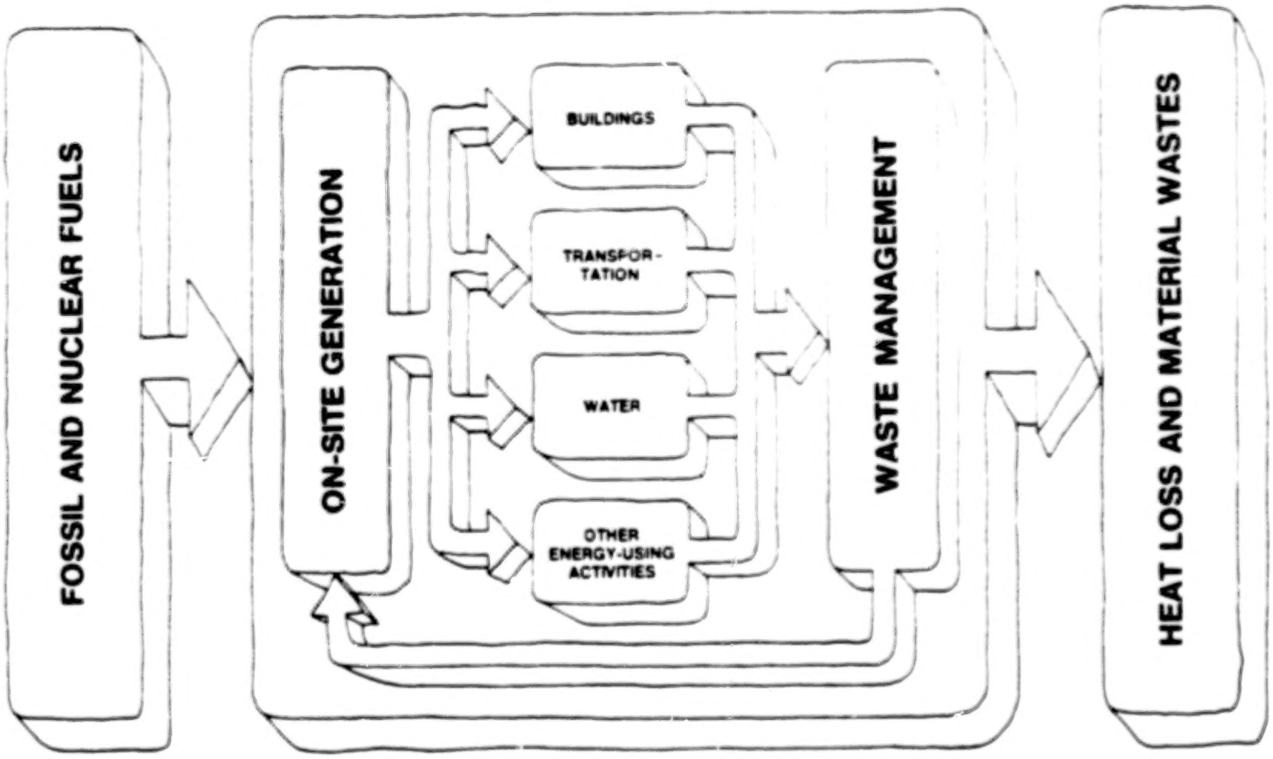
VOLUME II

SITE ENERGY-USING FUNCTIONS



ON-SITE GENERATION

Volume I of the Energy Conservation/Management program planning materials deals with the effective use of energy sources available at sites of the Fish and Wildlife Service (FWS). This volume discusses the general nature of on-site energy sources, and outlines a procedure for assessing opportunities for on-site generation of energy at FWS sites. The sources discussed briefly here in this introductory section and then in depth in subsequent chapters are:

- Wind
- Hydro
- Solar Thermal
- Biomass
- Cogeneration
- Photovoltaics

A section on storage and grid integration for on-site electrical production is also presented.

The materials in this volume are intended to provide important background information on each of the energy sources discussed so that a general assessment of opportunities for on-site generation can be performed. While energy conservation offers the greatest potential for immediate, short-term reduction of energy use and costs, scarcity and high cost of fossil and nuclear fuels over the longer term will call for a swift move to renewable energy sources, wherever they can be implemented cost-effectively.

Since these materials do not provide all the technical and cost information required for an engineering assessment of a particular technology, valuable sources of such information are referenced for those who require them. Sufficient information is provided in most of the following sections for a prefeasibility study -- an inventory of environmental conditions, production potential, and economics that will give you enough information to either eliminate or pursue applications at their sites. For full feasibility assessments, expert technical assistance is suggested. Many such applications will qualify as Special Demonstration Projects under the criteria established by the Department of Interior. They may also be eligible for funding under special grant programs established by the Department of Energy and other Federal agencies.

Replacing use of conventional fuels with renewable sources of energy is an objective of great national importance.

DEFINITIONS

On-site is a term which describes a set of technologies for converting natural energy flow to useful forms near where they will be used. Natural energy flows are precipitated by the sun and are manifest in winds, falling waters, and growing things, as well as in direct radiation. The ease with which these energies can be tapped varies by technology and specific site. In some cases the energy can be captured directly (as in solar hot water heating), but in wind and hydroelectrical energy generation, turbines and other highly developed technologies must be employed.

On-site generation can be included as part of an energy conservation plan because it reduces demand for traditional and scarce fuels. However, before any on-site technologies are employed to displace conventional fuels or to meet the energy needs of new facilities, you should identify all the ways that existing energy systems can be improved. The most abundant and least expensive energy source in the U.S. today is energy saved through conservation.

ON-SITE GENERATION

THE GENERAL NATURE OF ON-SITE ENERGY SOURCES

Decisions regarding on-site generation sources will require that you have some knowledge of the general characteristics of each source. It is important to remember that no one renewable energy source by itself can be considered a replacement for petroleum. Unrealistic expectations serve only to hinder the widespread use of solar, wind, hydro, wood and other renewable energy technologies. The technologies do work well together, however, and used together, they may well ultimately displace petroleum use. They also work well in combination with existing fuel technologies such as central power production, electric and oil heating, and all hot water heaters. The complementarity of on-site energy technologies with conventional systems could allow a smooth transition to an economy based on renewable energy production.

Secondly, although on-site energy technologies are more expensive initially than conventional systems, they are less expensive to operate because their fuel is, for the most part, free. Since a large proportion of the total cost (including operation) of conventional systems is the cost of fuel, cost comparisons of energy systems should be based on lifecycle costs. Fuel costs are increasing rapidly and are likely to continue to increase.

Third, on-site energy technologies share unique characteristics that you must consider in planning. Their value transcends traditional cost/benefit analyses and requires a review of your facility's role in public education. In most cases these technologies are refined, and the systems are commercially available, but their potential users have usually not had an opportunity to see the systems working. Having demonstration energy systems at your facility will accomplish the following:

1. It will meet part of your energy demand.
2. It will allow visitors to become familiar and more comfortable with renewable energy sources.
3. It will stimulate the market and help reduce the higher first cost of renewable energy systems for others.

One final incentive for implementing on-site energy generation technologies is rapidly increasing government support of their use. This support includes grants for specific applications, local tax exemptions, and Federal income tax credits. Because of this support, the cost to consumers is decreasing steadily. No investment in the proposed systems should be made without careful review of government incentives and assistance that may be applicable to your site and situation.

ADVANTAGES/DISADVANTAGES

On-site energy sources have several common advantages and disadvantages that you should be aware of. Their advantages include reduced threat to the environment, growth of employment, and the improved national economic situation that would result from reduced petroleum consumption. Such energy sources as direct solar and wind are virtually pollution-free and proven safe. They produce little or no air-polluting by-products compared to conventional oil and natural gas systems, and no long-term solid or gas systems, and no long-term solid or liquid toxins, unlike nuclear fission processes.

Preliminary investigation suggests that an economy based on renewable energy technologies would provide many more jobs than the current centralized petroleum economy. Reduced or displaced demand for imported fossil fuels would enhance the U.S. position in international relations, improve the balance of payments, and improve our image as an energy consuming nation.

Disadvantages include low-level environmental impacts. No one knows whether millions of windmills would change weather patterns. If there were numerous windmills, air circulation could be decreased over large portions of the land, perhaps affecting rainfall and air pollution levels. Certainly, even small-scale hydroelectric systems have negative environmental impacts. Building and installation costs and the intermittent nature of most of the sources are problems which must be addressed.

Solar collectors and wind machines must be installed with regard for aesthetic appearance, since new building design and retrofitted energy devices can clash dramatically with conventional buildings. The purity of appearance of a building or group of buildings being preserved for historical reasons might be diminished by the addition of solar collectors or wind towers. Zoning and building codes which are written without regard for widespread use of on-site energy systems may not deal directly with the potential energy system installation problems you will encounter.

END-USE MANAGEMENT

End-use management involves understanding the final, or end uses of energy, and then filling needs with the most appropriate forms of energy and conversion technology. Energy expert Amory Lovins pointed out the necessity for end-use management when he said that burning oil in central power stations at more than 1000°F in order to provide 70°F heat in a house is like "cutting butter with a chain saw." Use of solar thermal systems for heating domestic hot water, for instance, helps to preserve fuels for important high-intensity uses where they are irreplaceable. On-site energy technologies allow more appropriate matching of sources with end uses, and also reduce the losses of useful energy that result from transmission and transportation of energy over long distances.

ECONOMICS OF ON-SITE ENERGY GENERATION

Economics is a critical consideration in planning for on-site generation of energy. Unlike those of fossil fuel and nuclear-based systems, the costs of renewable energy systems are getting lower instead of higher, and there is no lack of fuel supplies for the renewable energy systems.

When considering the economics of energy systems, you must consider several factors:

1. First cost of installation is only one factor in making your decision. As previously suggested, you may want to install an on-site energy system for educational purposes.

2. If you install and use a hydroelectric system, and are comparing the economics of nonsubsidized hydro technology to the subsidized economics of existing fossil and nuclear

fuel technologies, you are considering only part of the total economic story. The fact is that government subsidies to central plant electric generation technologies account for much more of overall investment than those made by private industry.

3. The economics of renewable energy technologies for any given site varies with the specific use of the source and local energy costs.

4. Economics change over time. At a 14% annual increase in the cost of fossil and nuclear fuels, the value of investment in alternatives such as hydro will improve over time; however, there is no totally accurate way to establish the amortized costs of renewable energy systems without talking to manufacturers.

PRELIMINARY ASSESSMENTS

Now you are somewhat familiar with the nature of on-site energy sources, and of their disadvantages and advantages. Next, you need a more detailed introduction to the different technologies in order to make preliminary assessments at your site. Because the economics and availability of the hardware for on-site energy sources vary considerably, some general concepts may make the planning process easier.

Even though every one of the systems discussed in these pages is available and in widespread use somewhere in the world, some are clearly easier to buy, use, and maintain in current U.S. commercial market conditions. In terms of economics, for example, the payback on investment in on-site energy systems ranges from the shortest to the longest, generally as follows:

- Conservation and passive solar technologies
- Wood heating systems
- Solar hot water systems
- Hydroelectric systems
- Wind electric systems
- Active solar heat systems
- Bioconversion, photovoltaics, cogeneration, others.

This ranking may serve you as a rough guide when you begin to examine your site for potential on-site applications.

General economic ranking, however, does not deal with needs for education, environmental quality, or increased energy self-sufficiency. In addition, the ranking presumes many things, such as the availability of wood for wood heating systems, and the lack of availability of large masses of organic material for methane generation. On a farm where there are significant animal wastes and no forests, the payback on bioconversion might well be shorter than that for wood heating systems. Therefore, the decision to pursue any or all of these energy sources is, ultimately, a site-specific one.

The summaries are intended to provide a general introduction to each technology. More specific information on each source is provided in the core materials that accompany this section of the Planning Guide.

ON-SITE GENERATION

Wind

Harnessing on-site wind energy is the process of tapping the vast power of the wind either to do mechanical work or to generate electricity. The energy of air rising from dense to less dense conditions has been recognized and effectively captured for hundreds of purposes. The primary wind energy technology in the 20th century is electrical generation. Once the average wind speeds at a particular site have been identified, appropriate and available wind turbines with predictable output may be installed.

Much of the innovation in wind electric technologies has taken place outside the U.S. during the past 60 years because of our greater interest in larger, centralized power systems. As a result, wind electric technologies are not as familiar as some other on-site systems, such as solar hot water systems. Recently, however, a full range of wind machines, towers, and other hardware have become available in the U.S. In some cases long lead times may be expected for delivery of hardware. The machines have been used for varying lengths of time, and some are currently being tested for durability and efficiency by government agencies and private companies. For educational purposes, simple windmills are available that can be used as working models of energy concepts.

Reliable technical consultation is harder to find for installation of wind systems than for solar systems. There are fewer experts specializing in wind, but the organizations of wind energy professionals are excellent sources of information. There may also be minor legal, insurance, safety, and storage problems associated with wind electric conversion systems (WECS). However, the recognized potential for power from the wind, the positive economics, and the benign environmental impacts of wind systems make wind one of the most highly favored of the on-site technologies.

Hydro

Falling water has immense energy, hydropower, long used by mankind to do work. The power of moving water lies in its momentum and the distance it drops: the higher the drop, the greater the available energy. Hydropower sites already exist by the thousands in the U.S., where waterwheels once powered milling stones or saws and textile machinery. The technology has progressed from using large, cumbersome wheels to turn machinery to using modern, streamlined water turbines designed for the smallest waterfall or the largest man-made dam site.

There have been significant developments in small and standard-sized hydroelectric systems in recent years, although -- as with wind electric technologies -- hydroelectric systems are not as familiar to Americans as solar hot water systems. Several U.S. manufacturers offer small hydro turbines, although lead times for delivery may be a problem. At some sites, small-scale hydropower is competitive with electricity generated at central station power plants and provided by the local utility. As with wind electric systems, few experts have specialized in small-scale hydro systems, so that reliable technical consultation may be hard to find. However, guidance for planning and construction of hydroelectric systems may be obtained from public and private institutions and from the rapidly growing literature on the subject.

ON-SITE GENERATION

Solar Thermal

As used here, the term solar energy refers to technologies for the direct use of the sun's rays rather than those that indirectly use energy from the sun, such as wind, hydro or fossil fuel power. Solar energy processes capture the sun's radiation and retain heat for all thermal processes, although principal uses are for domestic hot water and the space heating of buildings. Although those with less sunshine often have higher conventional fuel costs, every site has some sunshine. This makes solar hot water systems economically competitive with conventional systems in many U.S. locations. Active solar heating and cooling systems are good investments for existing structures in very specific circumstances.

The temperatures required for domestic and commercial hot water uses and for space heating are easily reached with solar flat plate collectors. Steam and other high-temperature industrial needs can be met by using focusing collectors. Besides the collectors, critical elements of solar systems include provisions for storage capacity such as hot water tanks, automatic controls and the plumbing and heating supplies familiar to all licensed contractors. To guarantee 100% availability of hot water, most solar systems are installed so as to be compatible with a conventional heating system, which can be used for backup. Inexpensive solar hot water heaters for use during the warm months of the year are simple to construct and can be both effective and educational.

Passive use of the sun's energy in buildings generally requires the advice of an architect. Applications are quite site-specific, but for little cost, they can contribute major fuel savings. Passive solar ovens or simple greenhouses are also inexpensive means of illustrating the principles of direct use of solar energy. The solar industry is growing rapidly in the U.S., so that solar hardware and literature are readily available. Information on performance, costs, sizing, and paybacks can be obtained from solar firms listed in the Yellow Pages of the telephone book. There is now little or no lead time required for delivery of solar equipment. Financial incentives are available from Federal, State and local agencies. Many of the commercially available systems have been tested by government and independent testing facilities.

Caution is advised in dealing with the solar industry because many false claims have been made about system performance, probably more through enthusiasm than deceit. Solar hardware installers with good credentials are at a premium, and one of them must be located before acceptable installation and maintenance can be assured.

Biomass Energy

Biomass is a name for all plant matter; it is the source of nonfossil hydrocarbons which are the raw materials for making fossilized hydrocarbons, such as oil and natural gas, or for direct conversion to liquid and gas fuels. Biomass energy is released whenever plants are eaten, burned or converted to a usable fuel. Examples of biomass include trees, algae, and other foods consumed by animals. Wastes of all kinds, from forest residues to sewage, are also sources of biomass energy. Crops grown specifically for fuel in aquaculture or energy agriculture provide the necessary organic matter for such biofuels as methane (gas) or various alcohols (e.g., methanol or ethanol). The value of various sources of biomass energy depends on quantity available, ease of collection, and energy content.

Technologies for making usable fuels from biomass include digesters, stills, or highly sophisticated waste management systems. Among such systems operating in the world today are methane digesters that use human and animal wastes, distilling plants, and simple stoves or incinerators which make electricity.

The simplest and most economically attractive biomass energy systems are the stoves, furnaces, fireplace adapters, and other hardware used for burning wood. Although such systems are widely available and well known, their efficiency increases each year, and more high-quality systems are being manufactured in the U.S. than ever before. Consultation and guidance are available from manufacturers, local fire marshals, building inspectors, and public and private institutions such as state energy offices, university extension services, and hardware stores. These sources, plus agricultural consultants, forest rangers, and other wood experts can offer you tips on buying, planting, splitting, choosing, and storing wood. The literature on wood heating is extensive; installation is easily available; and maintenance, although critical, is simple. Wood stoves and furnaces can also serve as excellent educational tools for energy conservation.

Cogeneration

The term cogeneration usually describes the combined production of electricity and process heat. Technically, any system that uses the waste by-products of another is a cogeneration unit. The principle of cogeneration is illustrated by a pot of water boiling over a wood heating stove. Large-scale cogeneration of process heat and electricity has long been technically and economically feasible. Cogenerators were used extensively in the early years of the U.S. industrial era. Cogeneration accounted for about 30% of the U.S. electric power supply in 1930. It now accounts for less than 5%. In the more energy-efficient European countries, currently as much as 40% of the electrical supply is an industrial by-product. It is a straightforward process to measure and identify the quality and quantity of waste heat (or steam) in industrial or institutional processes. These calculations can then be used to design an electrical generation system fitted with predictable kW of capacity.

Photovoltaics

The direct conversion of sunlight to electricity is accomplished by photovoltaic cells. Photovoltaics are semiconductors that utilize chemical processes to create direct current (DC) when they are struck by the sun's rays. The cells are connected in series or in parallel, placed in solar panels, and are arranged to face the sun in solar arrays. DC created thereby is then converted to alternating current (AC) for direct use or grid integration, and battery packs can also be used for storage of electricity.

Most such solar cells are made of silicon, the second most abundant element on earth (obtained from sand, which is primarily silicon dioxide). The cells were originally developed for use in the U.S. space program. Their price has dropped dramatically during the past 20 years because of technological refinement and a wider range of uses. Remote applications of photovoltaics are already becoming economically competitive.

Photovoltaics is an exciting method of electrical generation which is undergoing continual improvement. Further rapid and significant price reductions are predicted within five years. With proper market stimulation, it is estimated that solar cells could supply an important percentage of U.S. electrical requirements by the year 2000. They could be producing significant amounts of the needed electricity within five to ten years.

Storage and Grid Integration

Successful implementation of on-site technologies for production of electricity may require use of storage and/or grid integration systems. This is because wind, water and sun are variable sources: The wind does not always blow, nor does the sun always shine. Matching output from these sources with demand often calls for storage or grid integration technologies.

Technologies for storing electric energy include batteries, pumped water systems, compressed air systems, hydrogen storage and flywheels. Of these, rechargeable batteries are the most universally applicable, and can be made compatible with power generation systems for any of the on-site sources. Although expensive, rechargeable batteries are readily available in most locations, and present only minimal installation problems.

The least expensive method for storing electricity from on-site sources is to feed power into the grid maintained by the local utility. Output of the generator must match line power in phase, frequency and voltage. Inverters must be used when direct current (DC) is generated on-site, and the grid provides alternating current (AC). Technical problems involved with grid integration should be relatively easy to resolve with the assistance of the utility's engineering staff or consulting engineers. A greater obstacle to implementation is obtaining agreement from the local utility to cooperate in such a plan.

CORE MATERIALS

This section of the Planning Guide has presented an overview of the most important technologies now available for on-site generation of energy. These brief summaries are amplified in the core materials on on-site generation that accompany the Guide. Each section provides historical background on the energy source and its use, a discussion of the technology, a presentation of its advantages and disadvantages, and a list of its potential applications. The sections also contain formulae and calculation techniques for assessing production potential, estimating the economics of implementation, and calculating payback periods. References are given to additional sources that will help you match your potential for on-site energy generation with your current and anticipated energy needs.

PLANNING PROCESS

On-site generation of energy is a logical part of your total energy conservation management plan. Implementation of on-site generation technologies will enable you to displace conventional fuels with alternative energy sources generated at your park, refuge or hatchery. Like the planning materials for other sections of the Planning Guide, the planning process presented in this section is intended to assist you to reduce the use of costly, nonrenewable fuels and power.

Each of the technologies discussed here is a proven means for converting energy from alternative sources into useful forms. After thorough planning and analysis, they must be properly applied to ensure economy and efficiency -- then they can help you significantly reduce consumption of fuels imported to your site.

We cannot overemphasize the point that on-site generation technologies should not be introduced at your refuge or hatchery until you have first undertaken the conservation measures identified in the other sections of the planning process. For instance, the efficiency of solar hot water heating equipment is considerably reduced if pipes and storage tanks are uninsulated. Further, you may find that by conservation actions, you reduce overall demand to such a point that the need for immediate implementation of on-site systems is removed.

One or more of the following technologies may offer an opportunity for producing energy at your site to offset, either totally or in part, your use of fossil fuels:

- windpower
- hydropower
- solar thermal
- photovoltaic
- cogeneration
- biomass conversion

This section of the Guide presents methods by which you can assess the potential of your site for the use of one or more of these technologies. A series of tables have been prepared to help you through the planning process.

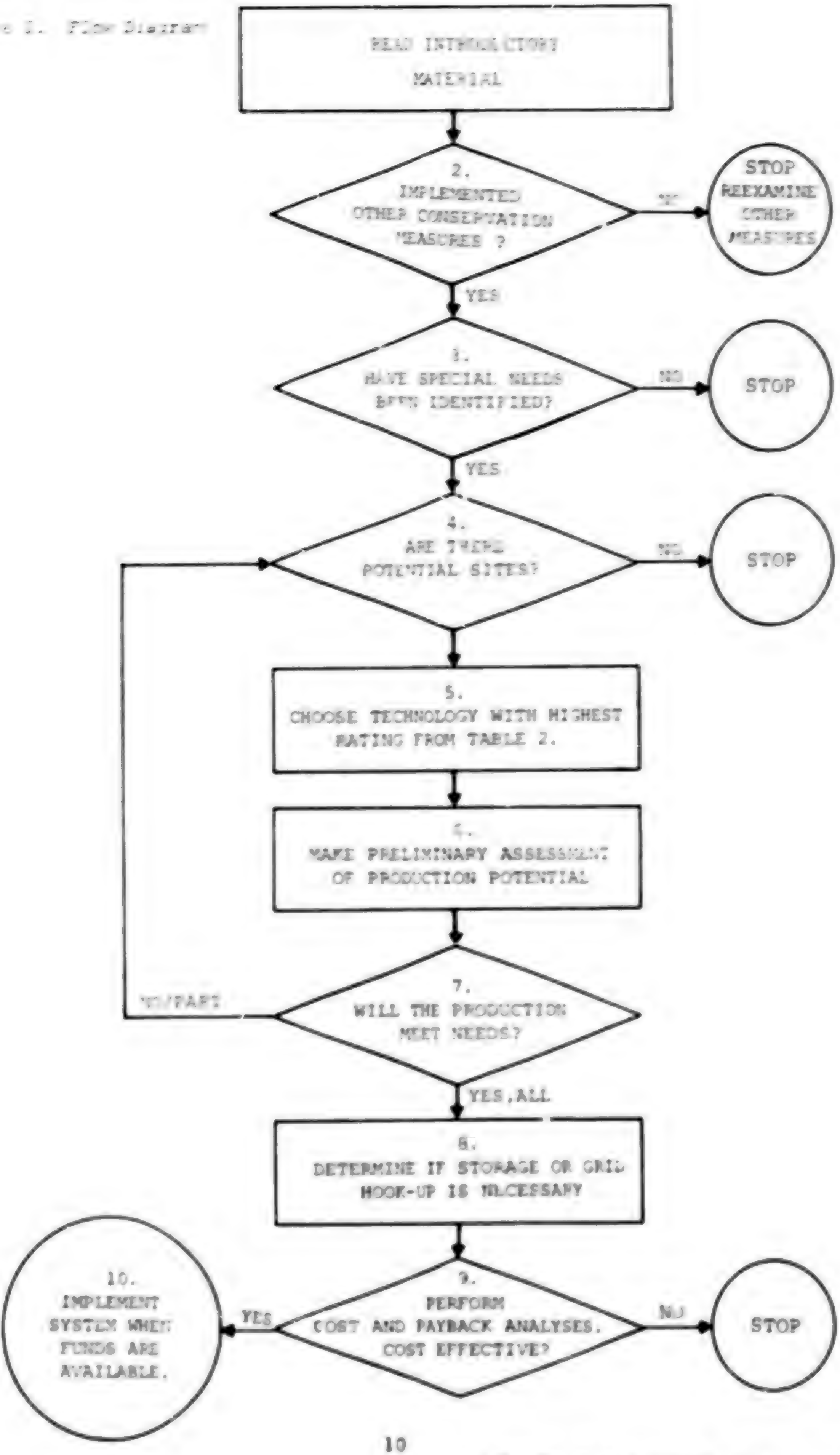
The process for collecting and analyzing the data, and determining production potential and the end use for that production involves a number of steps. However, the final results of your efforts could be a valuable contribution to saving energy at your site. Some of these technologies you may be able to implement yourself, especially systems on a limited scale such as the smaller, less sophisticated windmills, or simple flat plate solar collectors. For large-scale, highly productive systems, basic information is provided that will allow you to make a simple assessment. Afterwards, however, you will almost certainly require the assistance of technical experts trained in application of the specific systems under consideration. This can save many dollars in the long run.

The process for using on-site generation technologies at your refuge hatchery involves ten steps and is illustrated in the Flow diagram on page 13 (Figure I).

Step 1. Familiarize yourself with the concepts contained in the preceding pages on "On-Site Generation."

If you have not already read this material you should do so before continuing. It will introduce you to each on-site generation technology and provide a brief synopsis of the types of power available from each. It will provide useful definitions and give you a better understanding of the potential for on-site generation at your park, refuge or hatchery.

Figure 1. Flow Diagram


READ INTRODUCTORY MATERIAL
2. IMPLEMENTED OTHER CONSERVATION MEASURES ?
NO
STOP REEXAMINE OTHER MEASURES
YES
3. HAVE SPECIAL NEEDS BEEN IDENTIFIED?
NO
STOP
YES
4. ARE THERE POTENTIAL SITES?
NO
STOP
5. CHOOSE TECHNOLOGY WITH HIGHEST RATING FROM TABLE 2.
6. MAKE PRELIMINARY ASSESSMENT OF PRODUCTION POTENTIAL
7. WILL THE PRODUCTION MEET NEEDS?
NO/PART
YES, ALL
8. DETERMINE IF STORAGE OR GRID HOOK-UP IS NECESSARY
9. PERFORM COST AND PAYBACK ANALYSES. COST EFFECTIVE?
YES
10. IMPLEMENT SYSTEM WHEN FUNDS ARE AVAILABLE.
NO
STOP

Step 2. Be sure that cost-effective measures from the energy conservation sections have been identified and implementation plans developed.

It may be an ineffective use of funds and staff time to consider the installation of on-site generation systems before implementing potential conservation measures. You may, for instance, size a Wind Energy Conversion System (WECS) to meet an average power requirement of 15 kilowatts, based on usage, before examining the conservation measures. However, if conservation measures have been implemented, the average power requirements might be less than 10 kilowatts. If each kilowatt of power from the WECS costs $3,000, implementing conservation measures before sizing the WECS may save $15,000. A solar hot water system might not be able to provide enough heat to overcome the heat losses occurring through the walls of uninsulated pipes and storage tanks, but the same size system might easily supply all hot water needs if the pipes and tanks were well insulated.

Step 3. Assess energy and power requirements.

If you feel there might be a potential at your park, refuge or hatchery for on-site generation, use all the records available from the previous year(s) to determine the total power requirements for your site. Data Form 1, Preliminary Energy and Power Needs Assessment, will help you to display this information according to end use and total use. Since on-site technologies are available which produce power in amounts as low as milliwatts (mW=10^{-3}Watts) and as high as megawatts (MW=10^{6}Watts), the power requirements for different segments of the site, different facilities on the site, single functions, and single units should be determined wherever possible. Based on the understanding of specific technologies you developed reading the preceding material and your initial assessment of energy and power needs, match areas of need with potential on-site generation opportunities.

Step 4. Assess on-site generation opportunities and/or sites.

Use Data Form 2, Site Review, to make a preliminary assessment of the park, refuge or hatchery to locate sites for possible applications. The instructions for Data Form 2 describe some things to look for during the preliminary assessment. For further information on determining whether or not a site may be suitable, go to the "Required Environmental Conditions" and "Applications" subsections in the various sections of Volume II. The Reference Index (Data Form 4) in this section of the Planning Guide will give you the appropriate page numbers in these sections. Keep in mind that the intended site might not support a system producing sufficient power to operate the entire refuge or hatchery, but could support one producing enough to meet the demand from isolated facilities or units such as a power relay station or isolated traffic signals.

Step 5. Choose the highest-rated technology and read that section in Volume II, On-Site Generation.

Data Form 2, Column E will show you the technology you have rated highest. If you have not already read the section in Volume II discussing that technology while filling in Data Form 2, you should now read it very carefully to be aware of the advantages and disadvantages of the chosen technology and to better understand the possibilities for its implementation. You should also be aware of such things as water rights and usage, if you are interested in hydropower; of restrictions on changing the view in scenic areas if you are interested in a WECS; and of the potential pollution problems of a cogeneration system. Some of these problems will be mentioned in the subsection on advantages and disadvantages, but you should begin an inventory of specific considerations affecting the various technological applications at your site.

Step 6. Assess the production potential of the chosen technology.

If you are contemplating a small-scale system, you may be able to use the formulae in the appropriate section of Volume II and references cited there to make an adequate assessment of the production potential of a chosen site. However, for medium- or large-scale technologies, if qualified engineers are not on the staff, then outside help should be solicited to make the assessment. Some manufacturers of various on-site generation systems will make free estimates of production potential when they know there is the possibility of a sale. Care should be exercised to be sure that outside help has the required expertise to make an accurate computation of the production potential.

Step 7. Determine whether the chosen technology can meet all, part or none of the specified needs. Calculate the amount of present fuel use that would be displaced.

The production potential of specific sites may not be adequate to meet the particular needs you have identified in Data Form 1. In addition, the type of power output may not be appropriate for the particular need. For instance, you may have an anaerobic digester producing methane gas, but your power requirement is for electricity to operate lights and appliances. While the methane could very easily be used to heat water, cook, or provide space heat, the equipment needed to convert the methane gas to electricity may not be cost effective. In addition, the loss of power through conversion may be so great that the potential energy available is below that required for the lights and appliances. If the form of energy produced does not meet the requirement, no investment in the proposed on-site technology should be made unless you can meet other needs and displaced fuels from this process can then be shifted to the first specified need. Data Form 3 shows the end uses and/or products of each technology. From these end uses or products, the displaced fuels can be determined.

If the first technology chosen can supply part but not all of a specified power requirement, then you should go back to Step 4 and choose another potential technology. Follow Steps 4 through 7 again and again. On solar-powered systems, some sort of energy storage is needed because the power requirements may not always coincide with the periods of time when the wind is blowing or the sun is shining. Therefore, the power produced when the wind blows or the sun shines must be stored so that it can be used when demand exists.

Where a significant amount of power is produced intermittently and where arrangements can be made with the local utility, the best method of providing power continuously is tying the on-site generation system into the utility grid. If storage is required, read Section VIII, then prepare estimates of storage costs for use in the next step.

Step 8. Determine whether or not energy storage is required, or whether a tie-in to the local utility grid can be made.

For most intermittent systems, such as wind and solar-powered systems, some sort of energy storage is needed because the power requirements may not always coincide with the periods of time when the wind is blowing or the sun is shining. Therefore, the power produced when the wind blows or the sun shines must be stored so that it can be used when demand exists.

Where a significant amount of power is produced intermittently and where arrangements can be made with the local utility, the best method of providing power continuously is tying the on-site generation system into the utility grid. If storage is required, read Storage and Grid Integration Section, then prepare cost estimates for next step.

Step 9. Perform cost and payback analyses.

a) Refer to the subsection on "Economics" in the section that deals with the technology you're considering.

b) Using information provided there and in the reference materials, perform cost and payback analyses. (Note: Use the worksheet for simple payback period in the Buildings section of the Planning Guide.) Included in the cost and payback analyses should be such items as:

1. Installation costs, including land acquisition if required; equipment costs; labor; etc.
2. Maintenance and operating costs/savings if anticipated to be greater or less than present costs.
3. Costs of displaced fuels at current prices, and expected prices under current and anticipated rates of inflation.

c) Determine whether the system is cost effective or is required for other reasons. Demonstration of cost effectiveness is essential, since funds are more readily available if there will be energy and dollar savings and a short payback period than if savings in fuel costs are marginal and the payback period is long. However, if the present fuel is no longer available, changes must be made regardless of cost. If you have a system with a short payback period, or if energy is desperately needed, and there are potential on-site generation sites and technologies that can be utilized, the decision to go on to Step 10 is an easy one. If, however, the payback period is long, then you may decide not to proceed to Step 10.

Step 10. If the system is cost effective, or energy imperative, implement when funds become available.

For small-scale systems, site personnel may follow the plans presented in one or more of the reference books in the core library to build their own systems. They may also buy and install manufactured systems if the required engineering or technical talent is available on their staffs. In most cases, however, the best approach is to contract with specialists who understand the technology of interest.

INSTRUCTIONS FOR DATA FORM I
(Preliminary Energy and Power Needs Assessment)

For assistance in completing this table, you may want to refer to the energy use forms completed for the other sections of the Planning Guide Data from the "Preliminary Energy Audit" form, or the Energy Management Forms for Buildings, will be valuable for completing Rows A, B, and C. Be sure to convert all figures for energy use into the same units of measurement, such as kWh or Btu, so that you will be able to compare different needs, and compute cumulative totals. Complete conversion tables are presented in Appendix A.

For Row D (newly planned units), architectural and/or engineering specifications may provide the necessary information.

Row E (specific functions) refers to specific appliances, machines, or tools that might be powered by a small on-site generation system. The Appliance list in Table 1, of Appendix B, provides information on average electric consumption for most appliances. If the machine or appliance you wish to power is not listed, then the manufacturer's specifications on the label will furnish power requirement information, which when combined with the expected hours of use will provide kilowatt hours necessary for operation.

Row F (high use facility) refers to energy intensive installations, such as a pump house at a fish hatchery. Power for such an application might easily be supplied by a wind machine.

Data Form 2. Preliminary Energy and Power Needs Assessment

Power Required for / Facility	Lighting	General Appliances	Space Heating	Space Cooling	Hot Water	Water Pumping	Machines and Tools	Processing	Domestic	Other	Totals
(A) Park, Refuge or Hatchery											
(B) Isolated Facilities (Group of Bldgs., large bldg., etc.)											
(C) Small Isolated Units											
(D) New Planned Units											
(E) Specific Functions											
(F) High Use Facility											

INSTRUCTIONS FOR COMPLETING DATA FORM 3

(Preliminary Assessment of On-Site Generation Potential)

1. For assistance in completing this table, read the subsections entitled "Required Environmental Conditions", "Applications", and "Production Potential" for the technology you are examining. (Page numbers for those subsections are listed in Data Form 5.)

2. Consider the following items when assessing the various sites:

   a. For wind, list locations where the wind blows much of the time, with relatively unobstructed surroundings. Include such locations as tops of hills or mountains, valleys which channel wind, etc.

   b. For hydro, list any accessible site along a running stream.

   c. For solar thermal or photovoltaic, list each facility which has either a south facing roof or nearby accessible ground surface with an unobstructed southern exposure to the sun.

   d. For biomass:

      1. Digestion

         - list facilities which have the potential to produce usable quantities of organic sewage.
         - list sewage treatment facilities.
         - list facilities which have the potential to produce usable quantities of agricultural/aquacultural wastes.

      2. Incinerators or pyrolytic converters

         - list facilities which have the potential to produce usable quantities of wood wastes.
         - list facilities which have the potential to produce usable quantities of agricultural/aquacultural wastes.
         - list facilities that produce usable quantities of solid waste.

      3. Stoves/furnaces

         - list facilities which have the potential to produce usable quantities of wood or wood wastes.

e. For cogeneration:

  1. list any incinerator or thermal process facility that has the potential to produce steam to run generators.

  2. list any existing on-site generating system, such as diesel or steam generator from which neat could be extracted for space heating, hot water heating, or both.

3. Under Column A, fully describe the location of the site under consideration and list any obvious characteristics that may be applicable to the technology.

4. For Column B, make a preliminary assessment of whether the location looks promising for a large, medium or small scale system. Indicate this by placing a check in the column under large, or an M or S in the column under small/medium, for the technology under consideration. The following criteria may be helpful in determining the scale of wind and hydro sites:

  a. Locations where the average wind speed is greater than 12 mph can support large scale wind systems.

  b. Locations where the average wind speed is less than 12 mph but greater than 7 mph can support small scale wind systems.

  c. Large scale hydro sites are normally beyond the scope of park, refuge or hatchery interests. For medium scale hydropower applications choose accessible sites where small dams are already installed, or where a fast running stream has a drop of at least 3 meters (9.7 ft) in less than 30 meters (97 ft).

  d. For small scale hydro, list any accessible running stream, close to an energy-using facility.

5. For Column C, note whether you are considering electrical generation or mechanical power applications such as pumping water, grinding grain, etc., or whether usable solid, liquid or gaseous fuels will be produced.

6. In Column D, check whether storage is required and what kind (water, fuel or electric) or whether a tie-in with the local utility grid is under consideration. (Refer to Section VIII.)

7. For Column E, make a preliminary assessment of the site and/or technology based on your estimates of: (1) amount of energy that might be produced; (2) the ease of installation; (3) proximity of the using facility; (4) the expected costs; and (5) the appropriateness of the technological application to a specific facility or grid.

Factors to be considered in both 3 and 4 include, but are not limited to:

a. Historical Preservation Policies

b. Energy consumption patterns

c. Remoteness

d. Site plans

e. Budget

f. Condition of existing equipment.

After making your preliminary assessment, rate the site and/or technology on a scale of 1-5, with a rating of one (1) indicating a site or technology with the best potential for implementing an on-site generation system.

INSTRUCTIONS FOR COMPLETING Data Form 3

Code and Instructions

Use the following code to interpret Data Form 3:

● - The technology is a practical means of meeting the end use requirements or producing the required product.

0 - The technology can be used to meet the end use requirements or produce the required product, but will likely require intermediate steps or processes.

NOTES:

1 - Wind may produce hot water through friction devices.

2 - Wind may be used to operate mechanical pumps directly, or other machine tools through gears or a system of belts and pulleys.

3 - Hydrogen may be produced by the electricity from a WECS or hydroelectric system.

4 - Waterwheels may also be used to operate tools through gears or a system of belts and pulleys.

5 - Anaerobic digestion systems produce methane gas which can be further processed into methanol.

6 - These systems would only be applicable at large sites through a cogeneration system.

7 - By adding a water jacket to the chimney or heat exhaust system.

Under the "Other" column, less sophisticated uses are listed for the various technologies. Many of these uses or processes could serve a valuable educational purpose.

Upon determining from the table the most practical use of any on-site generation system, you can match the systems with the needs of the park, refuge or hatchery. You can then see which of the current fuels will be displaced and using the cost of these fuels, perform cost analyses.

Data Form 3. *Site Review*

			A	B		C	D	E
TECHNOLOGY		*ASSESSMENT*	*Potential Location (describe)*	*SCALE*		*Energy Potential Elec. Mech. Fuel*	*Storage Required?*	*Rating*
				Large	*Small*			
WIND POWER								
HYDROPOWER								
SOLAR THERMAL	*Hot Water Only*							
	Space Heating H.W. or Air							
	Other							
PHOTOVOLTAIC								
BIOMASS	*Digestion*							
	Thermal	*Incinerator*						
		Pyrolytic Converter						
		Stove/ Furnace						
COGENERATION								

INSTRUCTIONS FOR COMPLETING DATA FORM 4

Code and Instructions

Use the following code to interpret Data Form 4:

● - The technology is a practical means of meeting the end use requirements or producing the required product.

○ - The technology can be used to meet the end use requirements or produce the required product, but will likely require intermediate steps or processes.

NOTES:

1 - Wind may produce hot water through friction devices.

2 - Wind may be used to operate mechanical pumps directly, or other machine tools through gears or a system of belts and pulleys.

3 - Hydrogen may be produced by the electricity from a WECS or hydroelectric system.

4 - Waterwheels may also be used to operate tools through gears or a system of belts and pulleys.

5 - Anaerobic digestion systems produce methane gas which can be further processed into methanol.

6 - These systems would only be applicable at large sites through a cogeneration system.

7 - By adding a water jacket to the chimney or heat exhaust system.

Under the "Other" column, less sophisticated uses are listed for the various technologies. Many of these uses or processes could serve a valuable educational purpose.

Upon determining from the table the most practical use of any on-site generation system, you can match the systems with the needs of the park, refuge or hatchery. You can then see which of the current fuels will be displaced and using the cost of these fuels, perform cost analyses.

Data Form 4. *Code and Instructions*

TECHNOLOGY \ END USE OR PRODUCT			Utility Electric	Remote Electric	Hot Water	Space Heat	Mechanical Power (tools)	Gaseous Fuels	Liquid Fuels	Other
WIND POWER			●	●	1 ○		2 ●	3 ○		Milling, Grinding, etc.
HYDROPOWER			●	○			4 ○	3 ○		Milling, Grinding, etc.
SOLAR THERMAL	Hot Water				○					
	Space Heat H.W. or Air					○				
	Other									Distilling/ food drying/ evaporative cooling, cooking
PHOTOVOLTAIC			○	●						
BIOMASS	Digestion							●	5 ○	Soil Nutrients
	Combustion	Incinerator			○	○				
		Pyrolytic Converter	6 ○		7 ●	●		○	○	Solid fuels, oils, acids
		Stoves/ Furnaces & Boilers	6 ●		●	●				Cooking, baking
COGENERATION			6 ●		○	●				

Data Form 5. On-Site Generation Index (On-Site Generation, Volume II)

Technology / Topic	Wind	Hydro	Solar Thermal	Solar Electric	Cogeneration	Biomass
Technology	p.33	p.53	p.75	p.181	p.170	p.130,146,153
Advantages	p.34	p.60	p.80	p.181	p.72	p.134,147,156
Disadvantages	p.36	p.61	p.80	p.181	p.73	p.134,147,156
Size Calculation	p.43	p.63	p.90	p.182	p.173	p.137
Cost Information	p.43	p.67	p.99	p.184	p.174	p.137,150,158
Environmental Conditions (Site Selection)	p.38	p.62	p.82	p.182	p.173	
Applications	p.36	p.61	p.81	p.182	p.173	p.134,148
References	p.48	p.70	p.103	p.186	p.175	p.161

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Core Sources

DOE Facilities Solar Design Handbook. Springfield, Virginia: National Technical Information Service, 1978, 169 pp.

Eldridge, Frank, Wind Machines. Washington, D.C.: The Mitre Corp., 1976, G.P.O.#038-000-00272-4, 77 pp.

Installation Standards -- Solar. Vienna, VA: The Better Heating and Cooling Bureau, Sheet Metal and Air Conditioning Contractors' National Association, Inc., C. 1977.

Merrill, Richard, and Thomas Gage (eds.), Energy Primer. Menlo Park, CA: Portola Institute, C. 1978, 256 pp.

Montgomery, Richard H., with Jim Budnick, The Solar Decision Book. Midland, MI: Dow Corning Corp., C. 1978.

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ON-SITE GENERATION

Secondary Sources

Anderson, Bruce, with Michael Riordan, *The Solar Home Book: Heating, Cooling, and Designing with the Sun*. Harrisville, NH: Cheshire Books, C. 1976, 298 pp.

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McGuigan, Dermot, *Harnessing the Wind for Home Energy*. Charlotte, VT: Garden Way Publishing, C. 1978, 134 pp.

ON-SITE GENERATION

ABSTRACTS

Core Sources

DOE Facilities Solar Design Handbook. Springfield, Virginia: National Technical Information Service, 1978, 169 pp.

This handbook covers design of solar heating systems for commercial and laboratory buildings at Energy Research and Development Administration facilities. It includes discussions of solar energy fundamentals, solar heating and cooling technology systems and components, as well as a discussion of solar system economics. Quantitative analysis, with generalized design and sizing curves, is presented for solar heating so that collector and other system parameters can be cost-economically sized without a computer simulation.

Solar system design considerations and guidelines, as well as guidelines for developing subsystem specification, are present. Thus this handbook is both a primer for the solar novice and a reference manual for the solar system designer.

Wind Machines, Frank Eldridge, The Mitre Corp., Washington, D.C.: U.S. Government Printing Office, G.P.O. #038-000-00272-4, 1976, 77 pp.

This is a concise, technical document covering the history and future potential of wind machines, and of special interest, applications, siting, performance, and design of these systems. As part of the text, formulas are provided for figuring costs for energy produced, power in the windstream, and potential power performance by a wind machine. A list of suppliers is included.

Installation Standards -- Solar. Vienna, Virginia: The Better Heating and Cooling Bureau, Sheet Metal and Air Conditioning Contractors' National Association, Inc., C. 1977.

This publication provides installation standards for winter and/or summer heating and air conditioning systems and related systems, including solar. Preliminary data collection for load calculations and design and sizing leads the reader to equipment selection, construction, and installation. This step-by-step approach considers all the elements of heating and air conditioning systems, including duct construction and installation, liquids piping and installation, fuel and thermal energy storage, air cleaning devices, sound considerations, etc. Related systems include (solar) swimming pool heating and (solar) domestic water heating. Useful glossary, tables, and worksheets.

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Energy Primer, Richard Merrill and Thomas Gage (eds.). Menlo Park, CA: Portola Institute, C. 1978, 256 pp.

This primer stresses the need for integrating energy conservation with renewable energy systems. It is a comprehensive source book containing basic information on how different energy systems work, their limitations and potentials, useful references and available hardware. The technologies covered are solar, water, wind, biofuels (biomass, agriculture, aquaculture, methane, alcohol, and wood), and the prospects for integrating a number of technologies. Since it is written for the individual or small group only, small-scale systems are considered. Descriptions of such systems as windmills, wind generators, space heaters and dryers, wood burning heaters, and solar water heaters are given.

The Solar Decision Book, Richard H. Montgomery with Jim Budnick. Midland, MI: Dow Corning Corp., C. 1978.

In this excellent, well-organized, and beautifully illustrated book, a step-by-step decision-making process to narrow the solar options is presented. The 21 chapters (or decisions) range from recognizing that there is an energy shortage, to planning a solar system, to properly installing the system.

Many tables of cost, energy, and materials data are provided along with formulas to help you determine such things as operation and maintenance costs, what size pumps or collectors to use, and effectiveness of heat exchangers, to name a few. The appendix has much useful data on: (1) calculating structure heat loss, (2) evaluating an energy conservation investment, (3) determining what size system is needed for a given situation and site, and (4) judging what obstacles may shield collectors from the sun.

"The Dawning of Solar Cells," David Morris. Washington, D.C.: Institute for Local Self-Reliance, C. 1975, 16 pp.

This article can serve as a good introduction to solar cells, as it provides background material on what solar cells (photovoltaic cells) are, their costs, and technological breakthroughs. Their impact on the nation's electric needs is analyzed. Storage and backup energy systems are delineated.

On-Site Generation. Arlington, VA: National Recreation and Park Association, 1978.

This book is addressed to park, refuge, and fish hatchery staff. Six technologies are described, including wind, hydro, solar thermal, biomass, cogeneration, and photovoltaics. Methods for energy storage and grid integration are also provided. Advantages and disadvantages of each technology and how it might be applied to the site are discussed. The sections under each technology deal primarily with small- to medium-scale systems.

Means of computing potential energy production are offered for most sections. The appendices include conversion tables, electric appliance consumption tables and instructions for computing simple payback.

Producing Your Own Power, Carol Hupping Stoner (ed.). New York: Vintage Books, C. 1974, 322 pp.

Devoted to small-scale systems, this book discusses the limitations and potentials of such systems in harnessing energy from the sun, wind, water, wood, and organic wastes. The chapter on wind power considers means of generating electric power from the wind by using a system consisting of the wind-driven power plant, a storage system, conversion devices, and an optional backup system. In the chapter on water, small water power sites intended for small communities can be chosen based on a list of needed data provided in the text. Wood burners are described in terms of heating and cooking. Solar energy is utilized in this context for space heating and water heating, and these systems are described simply but with some design information included.

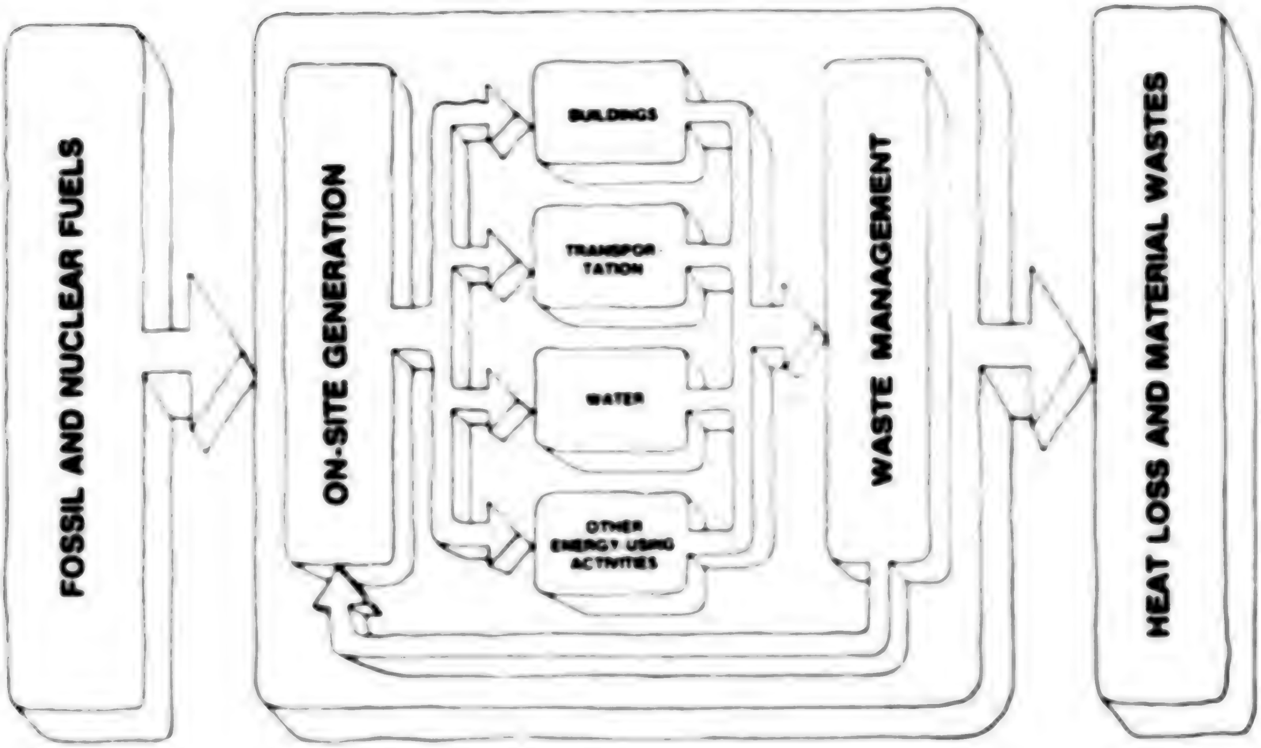
Following are detailed discussions of wind, hydropower, solar thermal, biomass, cogeneration, and photovoltaics. Except for biomass, they are examined from their historical and technical standpoints, followed by descriptions of their advantages and disadvantages, applications, environmental conditions required for their implementation, their production potential, and economics and sizing. References are supplied in each case for further information.

Biomass is discussed in terms of its sources, conversion technologies, anaerobic digestion, and combustion.

The last section deals with storage and grid integration of energy produced on site -- their technologies, applications, and economics.

The appendices supply conversion and equivalency tables, a chart for recording energy use and a table giving kilowatt ratings of appliances, and a method for calculating cost-payback periods for an on-site generation system.

Wind



SITE ENERGY-USING FUNCTIONS

WIND

INTRODUCTION

If all the earth's air were evenly whipped to a speed of 20 miles per hour, on one 60-second interval its force would equal the electrical energy generated by the Hoover Dam operating at full capacity night and day for 6,680 years.

-Christopher Finch
Quest '78 Magazine,
Jan/Feb Issue

Wind is a source of energy rich in tradition. Its history is double-edged and amusing, responsible for visions of "quaintness", like wooden shoes. In spite of recent advances in technology, wind has been considered a technology whose time had passed in the United States. As long as we continue to think of windmill technology as quaint or obsolete, the vast potential of the wind's energy will continue to pass us by.

The facts are that current wind energy technology is largely proven, commercially available, often economically competitive, and is being rapidly refined. The advantages of wind systems are being more widely appreciated and long-standing problems are being solved in an entirely professional, technical manner using technologies developed in aero-space science.

"What Happens When The Wind Dies Down?" is the question most often asked about wind energy systems. It is interesting to note that the wind, in certain locations, never does die down. Around the world, for example, there are winds whose constant presence has earned them such nicknames as the trade winds, the westerlies, the polar easterlies, the equatorial doldrums. Consistent winds may even exist at specific park, refuge, or hatchery sites. On an annual basis, winds are remarkably consistent all around the earth.

Winds are masses of air flowing from higher pressure into lower pressure areas. Lower pressure systems are less crowded because the air molecules have been heated by the sun causing them to move faster and the distance between molecules to increase and the air, therefore, to be less dense and lighter. As the warm air rises, cooler, higher pressure, more dense air flows in beneath it. As long as there are different air temperatures, there will be air flowing from the cooler, denser systems to warmer, less dense systems. The sun warms the air, and wind is the kinetic storage medium for solar energy in the atmosphere. Our weather is largely a function of winds, the earth's shape at the surface, and the turning of the earth.

Wind is an energy source with very important characteristics. It is abundant and will last as long as the sun shines. It is dispersed by nature and therefore does not have to be transported to a processing center. It is powerful. The wind power available in the continental U.S. is estimated at three thousand trillion kw or enough to produce 5 times the current U.S. demand for electricity.(1) It is clean. Wind power systems in operation emit no fumes or significant wastes. With the increasing demand for clean, renewable energy sources that create a minimum of environmental impact, wider use of wind energy systems in the future is a virtual certainty.

HISTORY

The references to windmills in 5,000 year old records from ancient Egypt make the technologies for capturing the power in moving air at least as old as recorded history. One manuscript mentions a Persian millwright in 644 A.D. whose windmill turned on a vertical axis to move water and grind flour. In today's terminology, we refer to wind "machines," since most "mill" work is no longer done by wind power.

Figure 1 illustrates wind machines whose blades turn on either the horizontal or vertical axis. The windmills that first appeared in Europe in the twelfth century were tilted on the axis 30 degrees to the horizontal, and the Dutch and other northern Europeans brought the sails up vertically. The most

WIND

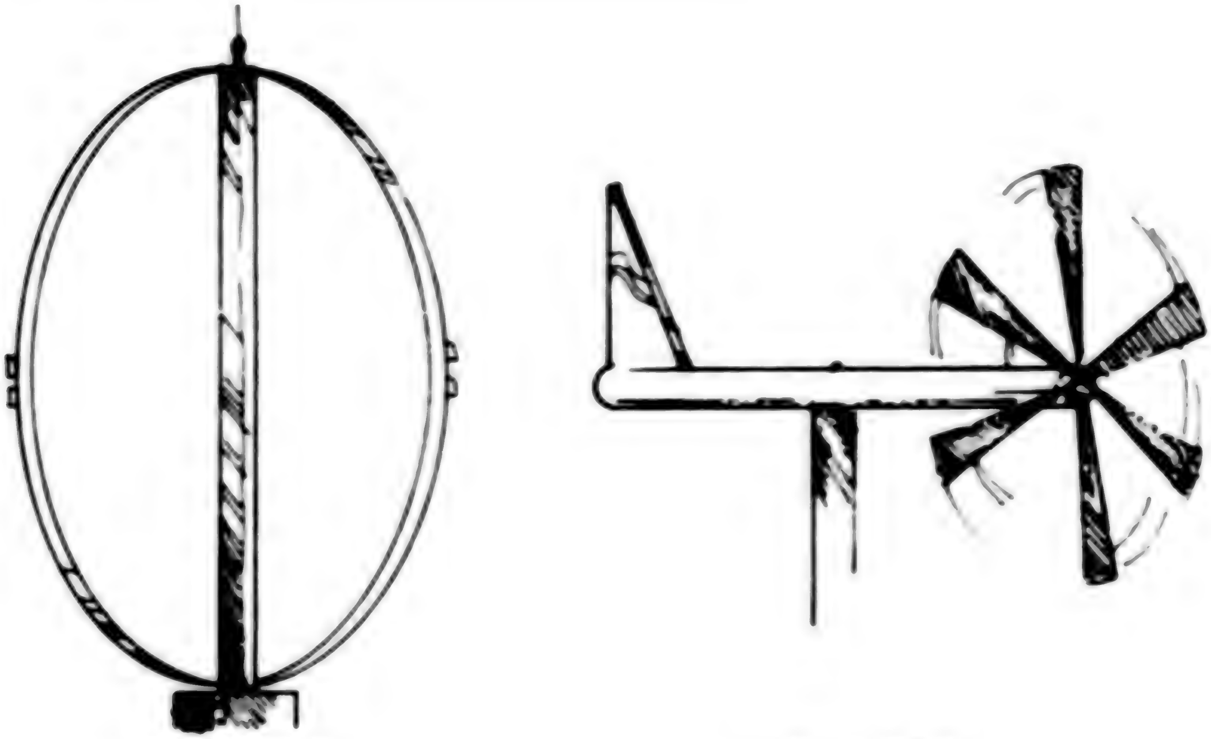


Figure 1. Wind Machines: Horizontal and Vertical Axes

famous horizontal axis wind machines are the windmills of the Netherlands. They were used not only for grinding, milling, sawing wood, and pumping water for irrigation and residential uses, but for draining wetlands, and reclaiming land from the ocean and bays. Using wind power, the Dutch drained large areas of land which lay below sea level, such as the Beemster and Schermer Polders, initially nothing more than dike enclosed bays and marshes. This reclamation increased the useful land mass of the country by 11%.

By the middle of the nineteenth century there were over 9,000 windmills in use in Holland, with some of the larger industrial mills delivering up to 90 horsepower (67.14 kw equivalent). This number decreased rapidly as steam replaced both wind and water as the major source of energy. By the beginning of the 20th century there were 2,500 windmills in use, and by 1960 only 1,000 were still operating.

The Danes were the first to produce electricity by wind, in 1888. By World War I the electric grid in Denmark had a total generating capacity of 100,000 kilowatts. German plans to construct a series of towers with 400 foot propellers (capable of generating 10-50 megawatts each) collapsed in the 1940s with the end of the Third Reich.

In the U.S., windmills were extremely important through most of the 19th century. Donald Carr reports that in 1850, "the use of windmills in the United States represented about 1.4 billion horse-power-hours of work, the equivalent of burning 11.8 million tons of coal!"(2) Twenty-five years later, U.S. wind capacity was cut in half and became less and less important as this country turned to coal, then petroleum, then natural gas and uranium because they were cheap and plentiful sources of power. Advertisements for windmills and parts were seen in the Sears-Roebuck catalogues in the 1920s. Although the wind never died down, interest in harnessing it did. In 1973, the Master Research Plan of the U.S. did not even mention wind technologies. Although data on the current use of wind power in the United States are not complete, it is estimated that there are 100,000 - 150,000 windmills running, the vast majority of them doing mechanical work in the midwest, southwest, and agricultural areas in other parts of the country. These are all that remain from the six million windmills built in the U.S. since the 1850s.

The largest wind energy conversion system (WECS) ever built was the Smith-Putnam wind turbine situated on Grandpa's Knob, Vermont. This machine, capable of producing 1.35 MW at 28.7 rpm, produced electricity intermittently from 1941 to 1945, feeding power directly into the distribution network of the Central Vermont Public Service Corporation. In 1945 the machine threw a blade due to metal fatigue and was closed down. Subsequent studies revealed that the electricity produced by the Smith-Putnam machine was not cost competitive with that produced by fossil fuel plants and it was decided that the wind turbine would not be started up again. Recent interest in WECS was sparked by the 1973 OPEC oil embargo, the subsequent rise in imported oil prices, and the growing realization that the U.S. must find an alternative to fossil fueled electrical plants.

Almost all government research being done on alternative energy resources in the U.S. is being handled by the Department of Energy (DOE). Prior to the creation of DOE, wind energy research was carried out under the auspices of several agencies. The Energy Research and Development Agency (ERDA) was responsible for the majority of the pre-DOE work, though some of the initial wind work in the early and mid-1970s was done by the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF), often jointly with ERDA. The first major step in ERDA's WECS program was the construction of the 100 kw ERDA-NASA experimental wind turbine at the NASA-Lewis Research Center in Plum Brook, Ohio. This machine, still being used by the DOE, is a downwind horizontal axis wind turbine. Its rotor is 125 feet in diameter and the machine is designed to produce its rated capacity of 100 kw at 40 rpm in 18 mph winds. The Lewis wind machine, put in operation in September 1975, serves basically as a testing apparatus to collect data about WECS hardware and control subsystems performance and cost.

The next step in the government research effort was for the DOE to install WECS directly into a utility grid. This was done in February, 1978, in Clayton, New Mexico where a DOE-NASA 200 kw wind turbine similar to the Lewis machine, began providing electricity directly for consumer use through existing utility networks. Two similar 200 kw wind turbines are expected to be erected shortly, one on Culebra Island, Puerto Rico, and one on Block Island, Rhode Island. These are to be followed by a 2.0 MW wind turbine tentatively sited for Boone, North Carolina. Similar machines are also scheduled to be placed at numerous other sites in the U.S.

In 1978, there are at least 120 smaller windmills in the U.S. that are used to generate electricity and interfaced with local utility grid systems. In the first half of 1978, the DOE showed significantly increased interest in smaller WECS. Contracts totalling $2.2 million were issued to seven U.S. companies to develop prototype wind turbine generators in the 1 kw to 8 kw range. Updated reports on federal wind energy programs are available from the DOE.

Two examples of significant social commitment to wind energy are found in California and Denmark. A recently approved program in California calls for 10% of the state's electric generating capacity to be wind powered by the year 2000. This amounts to 500 MW capacity installed by the mid-1980s, and 1000 MW by the 1995-2000 period.

In 1976, Denmark began a serious reintroduction of wind power, including installation of the largest WECS in the world. Research of world-wide importance is being done in Denmark, addressing the critical issues of storage, grid integration, and the complementary nature of wind and hydroelectric systems.

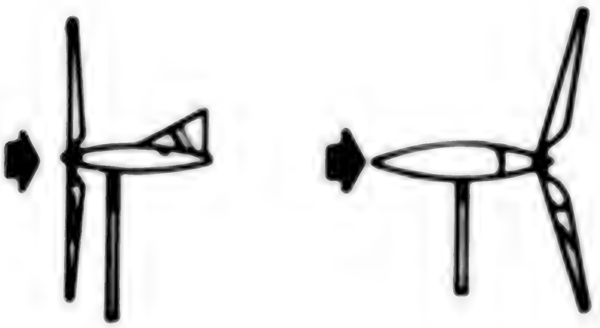
C. TECHNOLOGY

A wind machine system can be designed to do a number of tasks. The ancient windmills did mechanical work, turning stones to grind flour, pumping water for irrigation or land drainage, or to store it in lakes or reservoirs for later use. Today, mechanical energy is still required and wind powered energy systems are well-suited for such processes as compressing air, pumping water, stirring sewage during treatment, water circulation, ventilation -- as well as the age-old uses mentioned above.

The technology of wind energy conversion systems is not radically different from that of the oldest windmills. In either case the kinetic energy of the wind is converted by the machine into mechanical energy. This energy is then used to turn a generator (DC) or alternator (AC). Virtually all wind conversion systems in use or under study around the world use the process of rotation to convert the wind's energy (though other processes known to work include translation and oscillation).

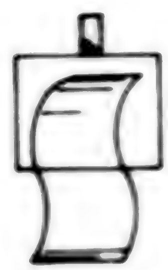
Windmills that use rotational conversion may be divided into three groups characterized by the orientation of the axis on which they turn. (See Figures 2, 3 and 4) Windmills of all three types have been used over hundreds, and in some cases thousands, of years.

Horizontal axis rotors, for the most part, utilize lift forces to extract energy from the wind. For a given area, lift forces provide many times more energy than drag forces. In most cases, devices using drag forces cannot move faster than the windstream speed. These factors combine to produce a much higher rotor tip speed to wind speed ratio for lift devices than for drag devices giving lift devices higher power to weight ratios and lower cost-to-power ratios.(3) The number of blades in horizontal axis wind turbines varies from a single blade with a counterweight to several dozen blades. Single blades are not widely



Up-Wind *Down-Wind*

Figure 2. Head-on Horizontal Rotors. The axis of rotation is parallel to the direction of the windstream (typical of conventional windmills).



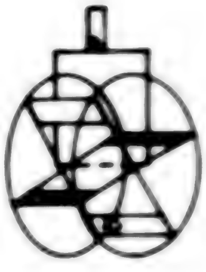
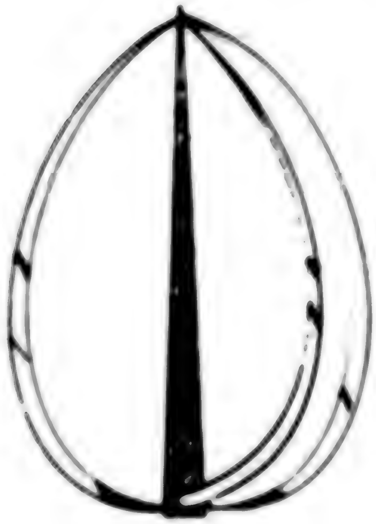


Figure 3. Cross-Wind Horizontal Axis Rotors. The axis of rotation is both horizontal to the surface of the earth and perpendicular to the direction of the windstream (similar to a waterwheel).



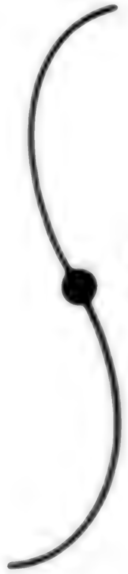


Figure 4. Vertical Axis Rotors. The axis of rotation if perpendicular to both the surface of the earth and the windstream ("eggbeater" type).

used due to the excessive vibration produced and frequent blade bending. Multi-bladed machines are often small scale, such as the one horsepower units used on farms and ranches throughout the U.S. to pump water or produce electricity.

Most of the existing and planned larger wind machines use a two blade rotor, the two blades lying in a straight line like an airplane propeller. The use of a two bladed rotor is normally dictated by cost. In large WECS blade costs are a substantial fraction of the total. Estimates for 100 kw wind machines based on NASA's early experience place blade cost at approximately 23% of the total.(3)

At present, little research is being done on crosswind (waterwheel type) horizontal rotor wind turbines because they "...have not been found to be very effective ..." and "...there appear to be no significant advantages to crosswind horizontal-axis rotors over either head-on or vertical axis rotors."(3)

If traditional horizontal axis windmills are uncommon sights, vertical axis rotor machines are yet more rare. The best researched and most thoroughly tested vertical axis wind turbines are the Savonius rotor and egg-beater-shaped Darrieus rotor wind turbines. These wind machines have an important advantage over horizontal axis machines, in that there is no need to keep the rotor of a vertical axis machine pointed into the wind. There are several economic advantages to these vertical wind machines. First, they are generally less complex and require no wind tracking hardware. Second, unlike the horizontal axis machine, the generator, gear box and control mechanisms can be at ground level, making installation and maintenance simpler and hence less costly, while reducing the need for additional tower support. The more efficient of the two is the Darrieus rotor, primarily because it utilizes lift forces like the head-on horizontal axis machine. The Savonius, on the other hand, relies on the forces of drag. The use of lift forces results in high efficiencies in the Darrieus, second only to those obtained by high-speed two-bladed horizontal axis machines.

Several total wind energy systems are illustrated in the following schematic. (Figure 5). Each WECS begins with electrical generation, deals with storage to make the energy available as much of the time as possible, determines AC and DC loads, and in some cases connects with supplementary systems.

The simplest use of wind generated electricity is in the form of Direct Current for appliances, lights, and tools. A battery pack is required, normally lead-acid batteries with the longest possible life (such as golf-cart or marine batteries, both deep cells). If the DC output is "inverted" an alternating current (AC) may be drawn off for radios and tools that require AC. If DC is to be used in the building or grounds, additional wiring is required, as AC lines will not carry the DC. The added expense may rule out direct use of DC.

Other storage media include flywheels, compressed air, pumped water, electrolysis, and more importantly, inversion for direct interface with existing utility lines. (Read the Section on Storage and Grid Integration, for more detail on the process of storing electricity generated on-site.)

ADVANTAGES / DISADVANTAGES

Advantages

The advantages of wind powered energy systems over centralized fossil or nuclear fueled systems are related to the environment, transmission, abundance of fuel, and other more subjective bonuses, such as increased self-sufficiency, displacement of imported fuels, and education.

1. Wind, where it exists, is free. Operating costs of wind machines are much lower than those of systems which utilize costly conventional fuels.
2. It is abundant because as long as the sun shines, winds are created.
3. It powers various conversion

hardware with no by-products to pollute the environment.

4. On-site wind energy systems create power near where it is used, so transmission losses are negligible.
5. The fuel for wind systems cannot be controlled by foreign nations and companies.
6. Wind systems are already less expensive than centrally generated electricity in very remote areas because of the high cost of new power lines.
7. Hardware that illustrates the principles of wind energy -- for educational purposes -- is inexpensive and easy to construct.
8. Some mechanical uses of wind energy, particularly water pumping, are long-proven technologies.

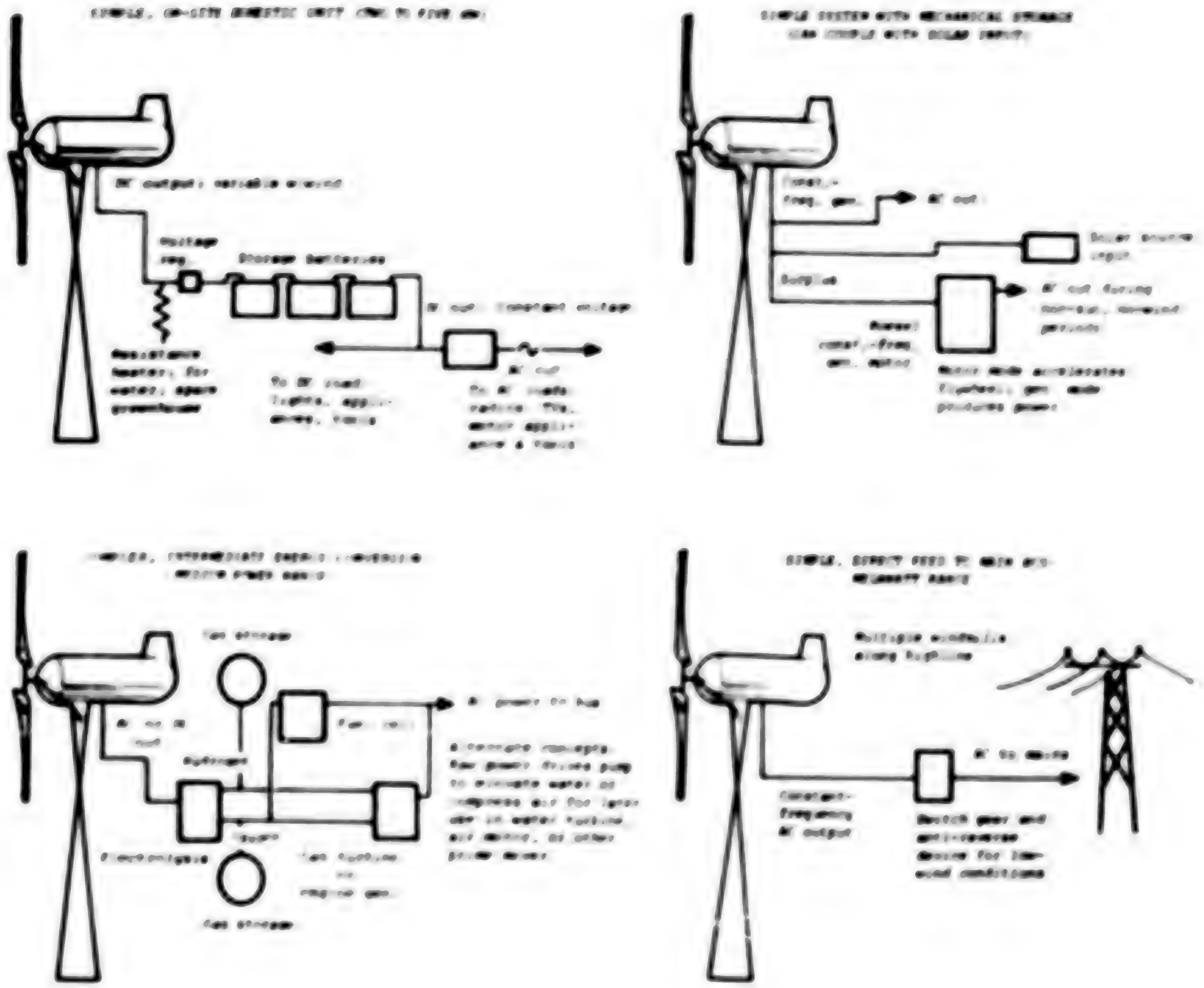

SIMPLE, ON-SITE DOMESTIC UNIT (ONE TO FIVE kW)
DC output; variable w/wind
Voltage reg.
Storage batteries
DC out: constant voltage
AC out
Resistance heater, for water, space greenhouse
To DC load: lights, appliances, tools
To AC loads: radios, TVs, motor appliances & tools
SIMPLE SYSTEM WITH MECHANICAL STORAGE (CAN COUPLE WITH SOLAR INPUT)
Const.-freq. gen.
AC out
Solar source input
Surplus
AC out during non-windy periods
Flywheel const.-freq. gen. motor
Motor mode accelerates flywheel; gen. mode produces power
Gas storage
Fuel cell
AC power to bus
Hydrogen
Oxygen
Electrolysis
Gas turbine or engine gen.
Gas storage
Multiple windmills along highline
AC to mains
Constant-frequency AC output
Switch gear and anti-reverse device for low-wind conditions

Figure 5. Total Wind Energy Systems

Disadvantages

There are, however, certain disadvantages to wind energy systems. They range from safety considerations, to economics, to the nature of the wind. Local wind installation experts are not as common as solar hot water experts, and far less common than washing machine repairmen. Other disadvantages include:

1. High speed propellers present some safety hazards to flying animals and to some degree to those people and habitats within range of a thrown blade.
2. Wind machines may generate interference that can be picked up on homeowners' radios and television sets.
3. The wind rarely blows constantly and with the same degree of power. Wind systems, therefore, must be regulated so damage is not done to appliances, and they must be backed up so power is available if the wind dies down.
4. First cost economic analyses may discourage the use of wind machines because the initial investment is high. Economic analyses of wind systems must be done on a life cycle basis. Wind systems are economic in many cases because there are no fuel costs.
5. Though wind tunneling effects are possible, both in natural conditions and those created by humans, wind is not easily captured and stored. Excess wind power may be stored for later use in the form of pumped water, batteries or hydrogen.

Changing economics are making wind generators competitive with conventional electrical generation sources. Research by both government and industry is leading to better wind energy hardware. Incentive programs are making the hardware more readily available. The bottom line is that the costs of small wind electrical and wind mechanical systems are dropping rapidly at a time when other energy costs are rising. The environmental benefits and the positive effects that large-scale use of wind will have on local employment and the U.S. economy are helping encourage efforts to minimize the disadvantages.

APPLICATIONS

Site plans to use wind energy systems should include surveys for both mechanical and electrical application. Mechanical applications are less expensive than WECS. Durable and effective wind machines may be built from indigenous materials by local labor or students, making an effective education project. WECS are of significant interest because electricity needs are as important today as mechanical and agricultural needs were years ago. Electrical demand is as high as 10 to 15 percent of total energy consumption in different parts of the country - and at the present rate is projected to make up a full 25% of total U.S. energy demand early in the 21st century.

Mechanical energy from the wind may be harnessed for many uses. These include:

1. Pumping water. Water pumps powered by wind have been available commercially for years. Wind-powered pumping can move water for domestic use, for irrigation, in fisheries, or to reclaim land in flooded areas. Water may be pumped uphill for use in hydropower applications. It may also be pumped above ground to supply gravity-fed toilets or for other uses in waste treatment processes.
2. Compressing Air. With the use of wind machines to run compressors, air can be stored under pressure in tanks or natural caves. This can be valuable for use in running machinery such as cow milkers or air hammers, and can also be successfully used as an energy storage medium (see Storage and Grid Integration, Section VIII).
3. Milling. This is the oldest application of the mechanical energy available from wind. Wind ma-

chines are often used for grinding grain, turning saw blades, threshing grain or crushing sugarcane.

4. Aeration. Wind power may be used to mix stagnant water or sewage to increase its oxygen content, and bacteriological activity.
5. Water heating. A mechanical process using the friction from wheels grinding together is now being tested and used where the availability of wind makes it cheaper than solar energy for hot water heating.
6. Moving air. Wind machines may move air through active and passive solar systems so that the need for electrical pumps may be avoided.

Electricity generated with wind systems may be used in the same ways as electricity from other sources, to power hot water heaters, lighting, machinery, tools, radios and televisions, electronic equipment, sewing machines, and refrigerators and air conditions. Usually, electrical applications call for some form of storage system (see Storage and Grid Integration). Briefly, storage needs can be met by a) direct grid subsidy, or b) battery storage. Direct grid subsidy involves connecting the onsite system with existing utility power lines. Battery storage, especially useful in remote regions where grid subsidy is impossible, can be designed to meet most conventional needs.

REQUIRED ENVIRONMENTAL CONDITIONS

At the most basic level, you must have wind, of course, and a need for the wind power generated. Strong, steady winds are the best. You should be aware that few available systems will be useful in winds averaging less than 10 mph. The nature of wind systems is such that you will need a site where gusts or ricocheting winds are few. You will also need to consider placing electric transmission lines from the generator to existing power lines, finding space for battery storage if yours is a remote location, and locating room at the site to make necessary maintenance and repairs.

The topography of the wind turbine site and adjacent areas should also be thoroughly studied. Wind systems should be situated so that there are no tall obstructions upwind from the site and that the neighboring terrain is level -- open plains or open shorelines. The windmill should also be placed at least 30 feet higher than nearby obstructions (buildings, trees) or 500 feet from them. Unless these general guidelines are followed, natural and man-made structures will disrupt the steady winds and subject the wind machine to stresses caused by gusts and ricochets. It is generally accepted that the least expensive way to get the greatest power from a windmill is to increase the height. The higher the tower, the greater the power available (See Paragraph C, TECHNOLOGY) the less wear on the machine, and the better the investment. Hilltops and the roofs of buildings are best. Valleys also are good locations except that wind will only be available from two directions.

PRODUCTION POTENTIAL

The following discussion lays out basic steps for assessing the production potential from wind energy at your site. The first step is to research wind energy information that is available from national and local sources. The second step is to perform basic measurements of wind conditions and potential at your site. The third step is to match the information you have on regional and local wind conditions with available information on wind machines for mechanical applications and WECS.

There are several national sources of wind data. The following map (Figure 6) of the U. S., for example, shows how wind velocities vary around the nation, from an average speed of 5 mph in some areas of California, Arizona, and New Mexico, to 36 mph for northern New Hampshire. You may contact the National Climatic Center, Asheville, N. C. 28801 for further information. NCC maintains data on a regional basis for average

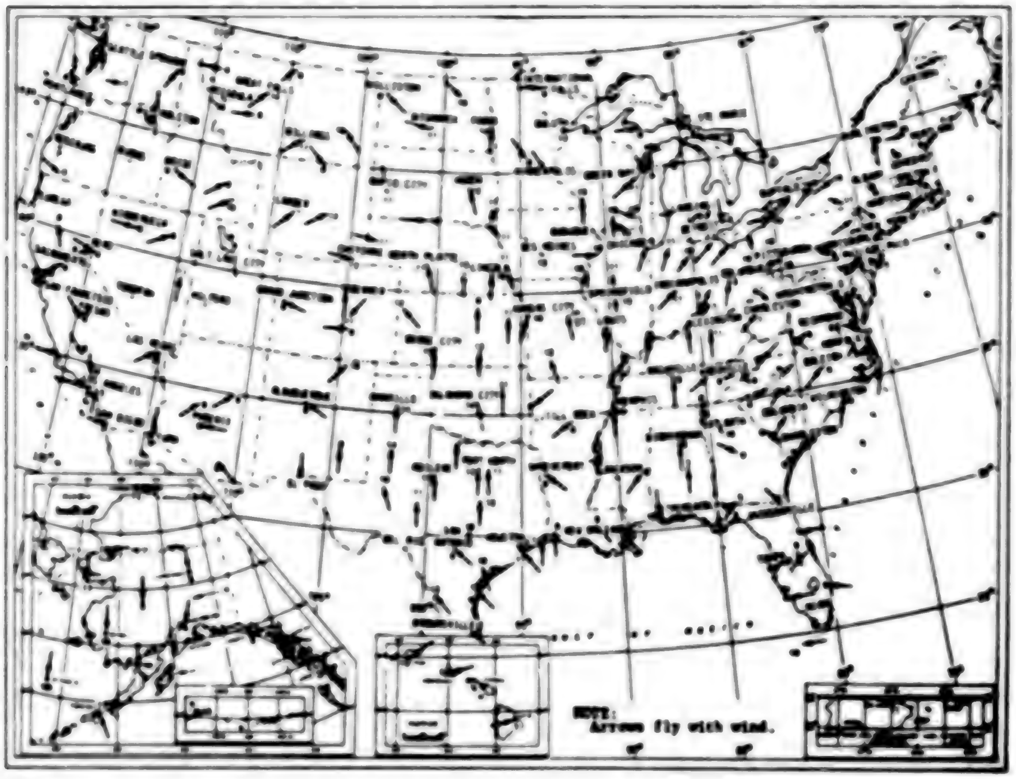


Figure 6. Mean wind velocities for various areas around the nation, including Alaska, Hawaii, and Puerto Rico and the Virgin Islands.

wind speeds, prevailing wind directions and other valuable points. It is important to get all the information NCC can give you about wind in your location.

Once you have obtained information from the NCC and other national sources, contact any possible local source. The more complete your information, the better, so go to as many possible sources as you can locate. These may include:

1. Local homeowners with windmills,
2. Local airports,
3. Local radio or television stations with meteorological devices,
4. Technical schools and colleges,
5. Private ski areas,
6. Nearby wind equipment manufacturers,
7. Military installations, and
8. Foresters, rangers and nearby farmers.

They may know of areas where winds seem to be high. You should also check out the history of windmills and other systems in your area, and look for any data that may have been recorded at your site.

When you have gathered together the existing information, you will be more fully prepared to make your own measurements. Because wind is intermittent and varies greatly in intensity at any given site, installing wind energy systems calls for exhaustive measurements and consideration of siting factors. The longer the period of time over which you take readings, the more often you take them, and the more accurate the wind-monitoring devices you use, the better will be the information you need for your decisions.

To prepare for making measurements, do some preliminary detective work, or wind prospecting. If you have no wind instruments, you can make very rough estimates by comparing the effect of wind blowing trees and bushes in a potential area with the wind measurement reported by the local weather service. However, to identify the best potential areas, utilize good equipment and review the facts presented above under Required Environmental Conditions. When you've identified the most likely spots, use an anemometer to take detailed readings. Anemometers may be purchased for approximately $100, or built inexpensively according to a method presented in Reference (4).

Ideally, wind data should be gathered on-site over a period of several years. Observations should be made for a year, if possible, and for several months at a minimum. Data should also be collected from different altitudes and locations at the same site. Move the anemometer instrument cups to different locations, or, better yet, get several anemometers and place them in different spots and elevations. Take daily readings, if possible.

As you make your measurements, seek to determine the following:

1. Average wind speeds, calculated for the different times of day and times of year. Knowing average wind speeds allows you to design systems for relatively continuous output.
2. How often the wind blows at higher than average speeds (the frequency curve).
3. Data on average wind speeds, etc., for different elevations at the same location.
4. Patterns of wind direction, and data on wind shifts and changes that occur frequently.

As you record information from your own measurements, compare your data with those you've obtained from NCC and other sources. Note consistencies and comparisons and extrapolate to calculate annual wind data for the site.

In making preliminary decisions on

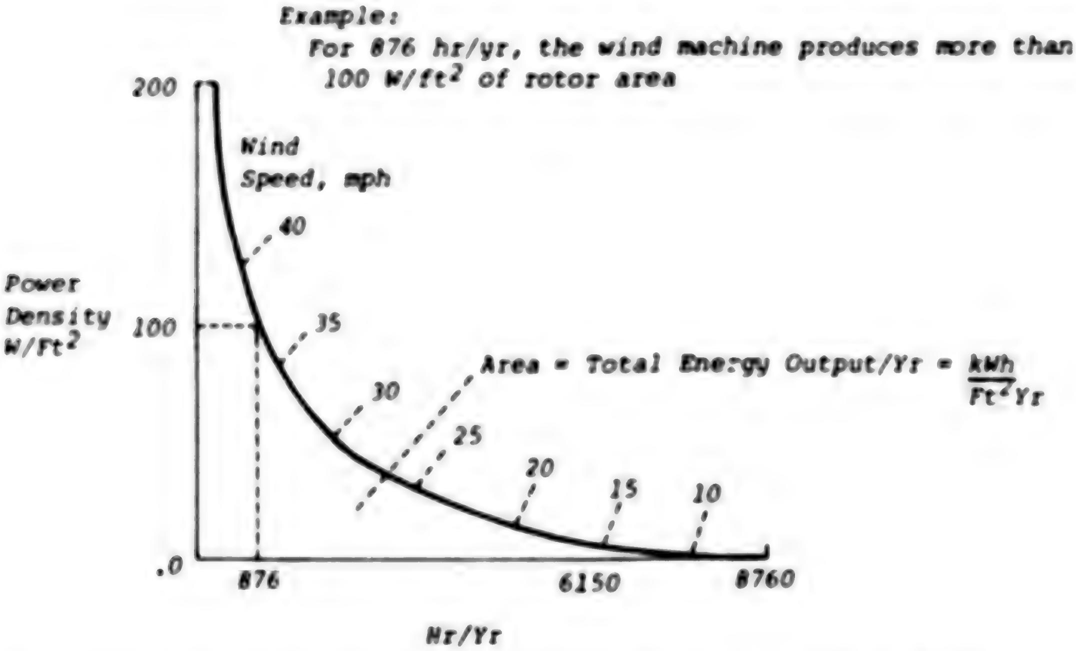


Figure 7. Theoretical Power Density Duration Curve For a WECS with $C_p=0.35$ (Source: Reference (3))

whether your site has adequate wind conditions for on-site energy production, there are several important factors to consider. First, wind systems except for the simplest mechanical devices, require at least 8 mph average wind speeds. Second, a difference of just a few miles per hour in the average wind speed can have a large effect on the power available at a particular site. Figure 7 graphically illustrates the rate at which power increases with increased wind speed for a wind energy conversion system with a power coefficient (C_p) of 0.35.

The graph in Figure 7 is good only for a WECS whose power coefficient (C_p) is 0.35. However, if you have collected data for at least one year at your site, you can draw your own power density duration curve for the power coefficient of any WECS using the following formula:

$$P_D = 5.64 \times 10^{-3} (V^3)(C_p).$$

Where P_D is the power density (the vertical left hand scale), C_p is the power coefficient, and 5.64×10^{-3} is a constant used to provide for a one square foot area and the units to make the answer read watts per square foot (W/ft^2). For example, if we use the C_p of 0.35 in Figure 7, and a wind speed of 37 mph, we have

$$P_D = 5.64 \times 10^{-3} (37)^3 (0.35)$$

$$= \underline{99.99 \text{ W/ft}^2}$$

which agrees with the graph.

Third, the availability of power from wind varies with the cube of the wind speed. This means that the vast majority of the power is contained in winds that blow at speeds above the average velocity. Estimates made by Sandia Laboratories put the actual power available at a site as being two to three times that which would be calculated by just using the annual mean wind velocity.(3) It will improve the accuracy of your estimations of power available at a specific site if you plot the annual average energy density of the wind versus the wind speed. The two graphs in Figure 8 show how much of the annual output of a wind system comes from the higher than average wind speeds.

Fourth, the power available from a wind machine varies proportionately with the square of the diameter of the swept area. A wind machine with blades 4 feet in diameter can produce four times the power of a wind machine with two foot blades.

Maximum useful power (P_m) can be determined by the following formula(5).

$$P_m = 2.4 \times 10^{-6} (D^2V^3)$$

where D is the propeller diameter in feet, V is the average wind speed in miles per hour (mph), and 2.4×10^{-6} is a constant which accounts for the density of air and the conversion of square feet-velocity cubed into kilowatts. The efficiency of even a well constructed wind system is usually no more than 50%, therefore, the actual power (P_a) available may be expressed as:

$$P_a = (2.4 \times 10^{-6})(D^2V^3)(0.5)$$

or

$$P_a = (1.2 \times 10^{-6})\ (D^2V^3)$$

Example: If D = 12 and V = 15 mph, then

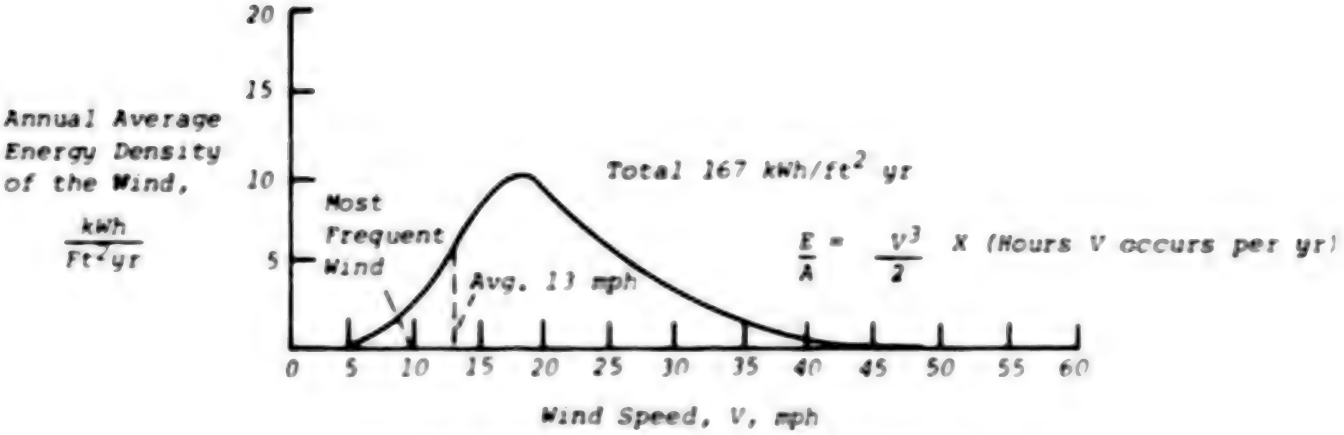
$$P_a = (1.2 \times 10^{-6})(12)^2\ (15)^3$$

$$= \underline{0.5832 \text{ kw}}$$

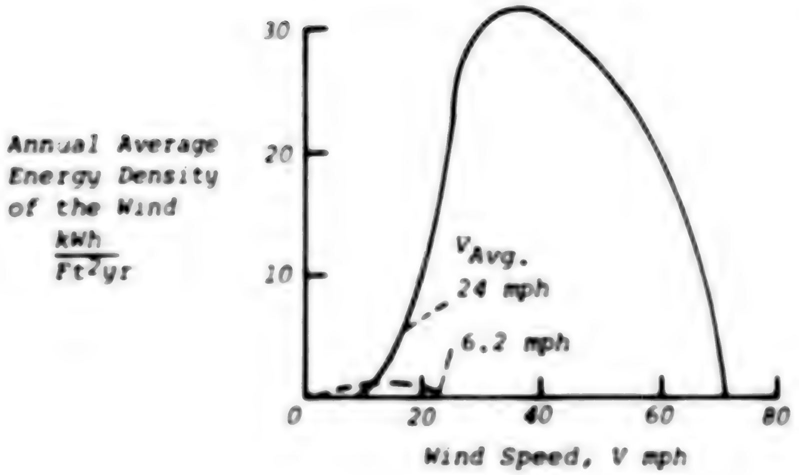
Fifth, altitude is an important consideration in the installation of any wind machine. As one's distance above ground level increases, wind speeds increase. For instance, climatological data from NCC show that the average wind speed at ground level in Connecticut is 9 mph, while the average wind speed at 150 feet above the ground is 10 mph. This increase varies with the roughness of the terrain. Power density decreases with altitude, due to decreased air density, but this is offset by the wind speed increases. For example, since the power available from wind varies with the cube of the wind speed, there is a 3.375 times as much power available to a WECS at 60 feet than at 25 feet, if the wind speed is 1.5 times as great. Therefore, by placing a wind turbine on a hill or high tower it may be possible to significantly increase its power output.

Sixth, the rated wind speed of the various available systems must be known. A wind machine chosen to match the average wind speed at a site will assure a relatively continuous output but will not tap the power in the higher wind speeds. A wind machine chosen for just the higher wind will only run a small fraction of the time. A trade off between these two considerations must be made. Most wind machines are designed for maximum rated output at a speed 35% above the annual mean. (6) For a site with 15 mph average wind speeds, a wind turbine would be rated at about 18 to 20 mph.

Seventh, and finally, buildings, mountains and other obstructions can cause wind conditions favorable or unfavorable for use. The tunneling effects



TYPICAL DISTRIBUTION OF ANNUAL AVERAGE ENERGY DENSITY OF WINDS OF VARIOUS SPEEDS



TYPICAL DISTRIBUTION OF ANNUAL AVERAGE ENERGY DENSITY OF WINDS FOR SITES WITH LOW AND HIGH ANNUAL AVERAGE WIND SPEEDS

Figure 8. Typical Annual Energy Output of Wind Systems

between buildings and in mountain valleys can provide strong, steady winds, as can convection currents which form on high walls. Figure 9 shows the effects of several kinds of obstructions on the potential for wind generation.

ECONOMICS AND SIZING

Once you know the average wind speeds on the site or at various locations of the site, you consider the appropriate size for a system. The following table (Table 1) gives an example of the output that may be expected from various wind speeds. It further gives an approximation of initial cost, even though every installation will vary with type of tower, height, amount of local labor available, and so on.

As a rule of thumb, the rated wind speed should be about 30% higher than the average wind speeds so that you may take advantage of the power in the wind moving faster than your average. The best way to size the wind system for

Table 1. Expected Output of Wind Systems

Rated Capacity	*Rated Wind Speed*	*Propeller Diameter*	*Approximate Cost**
.2 kw	*23 mph*	*7'*	*800*
.5 kw	*24 mph*	*6'*	*1,500*
1.0 kw	*25 mph*	*8½'*	*3,000*
1.5 kw	*25 mph*	*8'*	*4,000*
2.0 kw	*25 mph*	*13'*	*4,000*
2.5 kw	*40 mph*	*8'*	*4,000*
3.0 kw	*27 mph*	*14.5'*	*4,500*
6.0 kw	*26 mph*	*16.4'*	*8,000*
10.0 kw	*25 mph*	*25'*	*15,000*
15.0 kw	*26 mph*	*25'*	*20,000*
20.0 kw	*28 mph*	*25'*	*20,000*

**System including tower, etc.*

Rated Capacity: In order to compare different sizes of wind electric systems, all manufacturers provide an output rating called the rated capacity. Since the output varies with wind speed, the output is given in conjunction with the rated wind speed. In other words, either one of the first two columns in the table is meaningless without the other.

Rated Wind Speed: The rated wind speed qualifies the rated output or rated capacity. To read the table, say "System number one is rated at .2 kw (200 watts) at a wind speed of 23 mph."

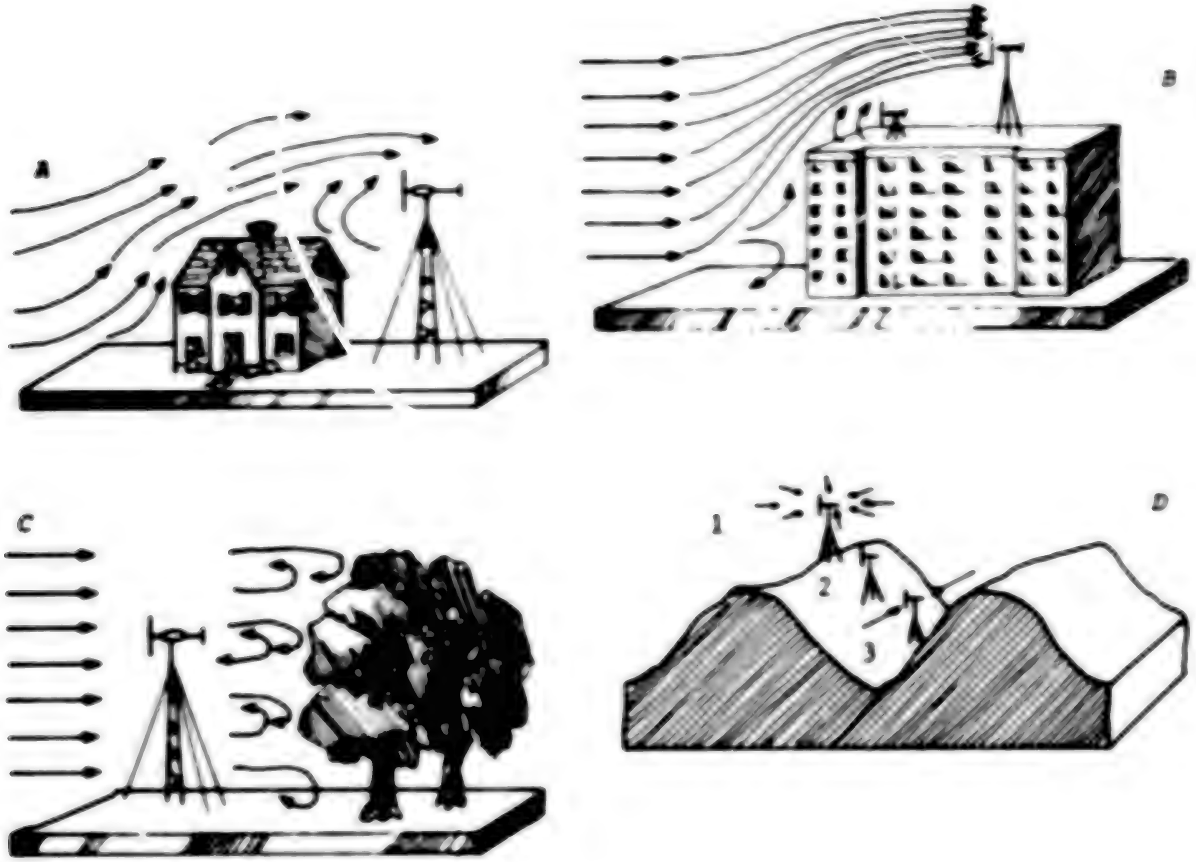


Figure 9. Effects of Obstruction on Potential for Wind Generation
A - The house is diverting the windstream above the generator, which should either be raised or moved. B - Again, the building is diverting the wind stream from generator 1, actually increasing the windspeed for generator 2. C - Obstructions cause wind turbulence whether they are in front of or behind the generator, as here. The mast should be extended 20-30 feet above the trees or sited 300-500 feet away from them. D - Boundary considerations may rule out the best sites in hilly country. #1 is the ideal; it benefits from all wind directions. #2 is not recommended; #3 is a good site for wind coming from two directions only.
(Source: Reference (5))

your site is to have complete data. In the example given above, the 2 kw system is probably well suited for average wind speeds around 19 mph.

Other considerations are discussed below:

1. Know what maximum winds you can expect. Systems are assessed for their ability to withstand certain gusts and no more. Towers must also be constructed to withstand the wind.
2. Remember that various electrical systems may utilize the energy generated by windmills. Some lights and appliances that run on DC are available; battery storage systems are expensive but important for remote applications. The best suited system is probably a synchronous inverter so that nearly all (95%) of the electricity generated may be used or stored in the local utility's grid (refer to Storage and Grid Integration, Section VIII).
3. Prices change very quickly, so it is best to check with manufacturers directly. For information on dealers, check references such as the *Energy Primer*.(7)
4. Generally, each usable 1,000 kwh per month of wind generated electricity will cost about $3,000 to install. Check your demand calculations using Tables 1 and 2, Appendix B. A refrigerator (15 cu. ft.) draws almost 100 kwh per month. Add a small TV, radio, clothes washer, and lighting for five to seven rooms, and your electrical demand is about 300 kwh per month, then you can expect to spend close to $3,000 -- depending on available wind, tower height, and other features. The cost of electricity in your region is a major factor in making a decision. U.S. electric rates varied regionally from 1.5 to 11 cents per kwh in 1978.

The figures in Table 2, columns G and H, give examples of calculated payback periods for each of the systems sized in Table 1. More accurate analyses are available from representatives of the wind industry, often free of charge. It will be helpful to contact the nearest wind consultant, manufacturer, or research group. Identifying them may mean contacting the state energy office, the regional branch of the Department of Energy, or the American Wind Energy Association, Washington, D.C.

Table 2 shows the calculated payback period in years for WECS of different power outputs and costs. Column A shows the output for the WECS at the rated windspeed (Column B). Column C gives the expected output for average windspeeds of 15 mph and multiplying the output from Column C by the number of hours per year (8760) gives Column D. Column E is the approximate costs, which when divided by 15 times Column D gives the cost per kilowatt hour for a 15 year life cycle (Column F). For example, the usable output for the 0.5 kw WECS is 1068.7 kwh/yr. Over 15 years, the usable output is 16,030.5 kwh and the approximate cost is $1,500, therefore, the cost/kwh over 15 years is:

$$\$/\text{kwh} = \frac{\$1{,}500}{16{,}030.5\ \text{kwh}} = \underline{0.094\ \$/\text{kwh}}$$

These figures reflect no estimate of maintenance costs for either existing or newly installed WECS.

Columns G and H show estimated payback periods in years for the systems, given different costs per kilowatt hours of electricity provided from other sources. The figures in Column G have been calculated using a zero inflation rate, while those in Column F show payback with a rate of inflation in electric costs of 10% per year. The figures in Column G were computed as follows:

Usable kwh/year, Column D for the 0.2 kw system are 481.8 kwh.

Selecting a current cost/kwh of $0.015, we have:

(481.8 kwh/year)($0.015/kwh)

= $7.23/yr.

The system, installed, costs approxi-

Table 2. Estimated Payback Periods in Years for Wind Systems of Different Power Outputs.

(A)	(B)	(C)	(D)	(E)	(F)	(G)					(H)				
Rated Output (kw)	Rated Wind (mph)	Output for 15mph Avg. Wind (kw)	Usable kwh/yr	Approx. Cost of System ($)	Cost/kwh Spread Over 15 yrs	No Inflation Payback Period (yrs)					10% Inflation Payback period (yrs)				
						$/kwh					$/kwh				
						0.015	0.03	0.04	0.06	0.10	0.015	0.03	0.04	0.06	0.10
0.2	23	0.055	481.8	800	0.111	110.7	55.3	41.5	27.7	16.1	26.7	19.8	17.3	14.0	10.4
0.5	24	0.122	1068.7	1,500	0.094	93.6	46.8	35.1	23.4	14.0	24.6	18.3	15.9	12.7	9.3
1.0	25	0.216	1892.2	3,000	0.106	105.7	52.8	39.6	26.4	15.9	25.8	19.4	16.9	13.7	10.1
1.5	25	0.324	2838.2	4,000	0.094	94.0	47.0	35.2	23.5	14.1	24.7	18.4	15.9	12.8	9.9
2.0	25	0.432	3784.3	4,000	0.070	70.5	35.2	26.4	17.6	10.6	22.0	15.9	13.6	10.7	7.6
2.5	40	0.132	1156.3	4,000	0.231	230.6	115.3	86.5	57.7	34.6	33.5	26.6	23.9	20.2	15.8
3.0	27	0.514	4502.6	4,500	0.067	66.6	33.3	25.0	16.7	10.0	21.5	15.5	13.2	10.4	7.3
6.0	26	1.152	10091.5	8,000	0.053	52.8	26.4	19.8	13.2	7.9	19.4	13.7	11.5	8.9	6.2
10.0	25	2.160	18921.6	15,000	0.053	52.8	26.4	19.8	13.2	7.9	19.4	13.7	11.5	8.9	6.2
15.0	26	2.880	25228.8	20,000	0.053	52.8	26.4	19.8	13.2	7.9	19.4	13.7	11.5	8.9	6.2
20.0	28	3.075	26937.0	20,000	0.049	49.5	24.7	18.6	12.4	7.4	18.8	13.2	11.1	8.5	5.9

mately $800.00, therefore, to compute simple payback, divide the cost by the first year savings:

$$\frac{\$800.00}{\$\ 7.13/\text{yr.}} = 110.7 \text{ years}$$

Accordingly, the figure of 110.7 years is found under the column for electricity priced at $0.015/kwh. Payback on the same system at the same price per kilowatt hour for the first year, but given an annual inflation rate of 10%, will be 26.7 years -- a little less than one quarter the time at zero inflation. (Formulae for calculating the payback period at 10% inflation may be found in Appendix C).

WIND

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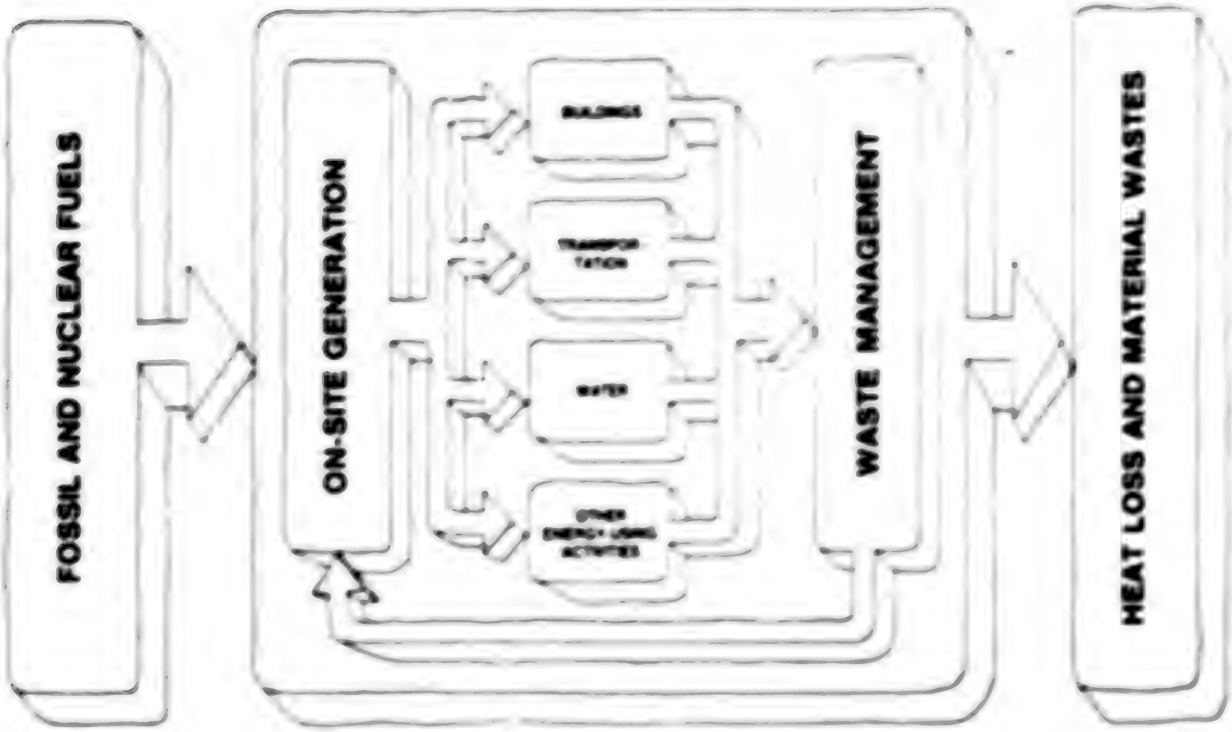
Hydropower



SITE ENERGY-USING FUNCTIONS

HYDROPOWER

INTRODUCTION

> *The use of water power in mechanical forms is one of the most natural habits of the human race. Probably the mill wheel preceded the vehicular wheel as a human concept.*
>
> *-Donald Carr*
> *Energy and the Earth Machine*

Leonardo da Vinci saw water as the busiest of substances. He called it "the element that knows no rest." Like wind, water has been used to provide humans with energy for thousands of years. It provided the world's first highways and still serves as a form of cooling for animals and people suffering the effects of warm weather. Its abundance is only outdone by its magnificient, raw, mechanical strength, as illustrated by such disasters as flood and tidal wave. The absence of water is life-threatening. Droughts and fires are unhappy testimonies to the importance of water to every element of life. Almost everyone has witnessed the destruction caused by torrential floods, the subtleties of weathering or erosion, the power of wave motion, the strength and mystique of grand rivers, or the gentleness and swiftness of small streams. The power of water has the capacity for both destruction and useful work.

Water power is a form of solar energy. The sun begins the hydrologic cycle by evaporating water from lakes and oceans and then heating the air. The hot air then rises over the water, carrying moisture with it to land. The potential energy of the water is dissipated as the water rushes or meanders on the way back to lakes and oceans.(1)

Hydro(water)power is useful energy derived from the movement of masses of water. Two forces are responsible for the movement of water on the earth's surface: 1) the falling of streams through the force of gravity; and 2) the rising and falling of tides through the force of lunar and solar gravitation. Tapping the tides for usable energy is generally a large-scale, capital intensive technology and will not be discussed here.

The amount of energy recoverable from rivers, streams, and lakes is an enormous, almost incalculable quantity. It may be that only a tiny portion of the available water power is suitable for harnessing, but in the U.S. alone the potential has been estimated as tens of thousands of megawatts.(2) Recent studies by the Army Corps of Engineers and the Federal Power Commission indicate that at least 10% of the present U.S. electrical capacity could be produced by retrofitting existing small recreational dams.(3) Any park, refuge, or hatchery which has a river, stream, lake, or reservoir has a potential source of electrical or mechanical hydropower.

Because water can be easily manipulated or controlled by dams, energy storage is less of an obstacle than in some other on-site sources such as wind. In addition, water has qualities well suited to complementary or "hybrid" systems such as pumped storage, currently being used to aid electricity suppliers during peak demand periods. One study on the subject has shown that Denmark's periods of lowest wind activity correspond to northern Scandinavia's late spring run-off and full reservoir period. The Scandinavian countries are making plans to use water-generated energy to compensate for periods when wind-generated energy is scarce.(4)

For those looking for a source of "homemade" power, flowing water may generate a picture of easily captured, free energy. However, getting useful energy from water can be expensive, and there are also other factors to be considered before damming a river or stream. Costs will be lower if the head (vertical distance the water falls) is relatively high, and produces a long fall so that all or part of the falling water can pass through a turbine without the need for a dam. Conversely, costs will be higher when the body of water produces a head of 20 feet or less and a new dam is required.(5)

Unlike wind, water power technologies have never been forgotten or disregarded. It is not being used extensively in the U.S. today due to the environmental impacts of large scale installations and the competitive advantage formerly held by cheap and readily available fossil fuels. The rapid depletion of world fossil and nuclear fuel reserves and the consequent rise in the price of these fuels make hydropower more competitive. Advances in smaller scale hydro technology and the improvement in environmental management techniques are also making hydropower more attractive.

HISTORY

Hydropower may be the oldest of the energy generating technologies we discuss. The strength of water has impressed every generation since the beginning of time and was probably tapped long before recorded history. Simple water wheels were first turned for mechanical processes like grinding grain and later for powering saws and other tools.

Waterwheels themselves have become more sophisticated, durable, and efficient as hydropower technology has matured. Hero of Alexandria is credited with inventing the earliest reaction-type turbine, ca. 100B.C. Refinements of later technologies of the undershot wheel led ultimately to the Pelton or impulse turbine.

In the early 19th century, the hydraulic ram was invented to use the power from falling water to force a small portion of the water to a height much greater than the source. Since no external power is needed, the hydraulic ram can be used in remote areas to pump water from low streams to irrigate fields and water livestock, as well as provide water for homes. Plans for home-built hydraulic rams and references for manufacturers are listed in the references.

Use of water power has been universal where mountain communities would take advantage of high head conditions to utilize current technologies for small and medium hydroelectric plants. Small scale hydro technologies were once very important in this country. At the turn of the century over 100 manufacturers were producing commercially available units, while in 1976 there was only one such manufacturer.

Hydroelectricity is a relatively recent technology. Development, refinement, first applications, and widespread use all occurred in the 19th century. Most of the refining of water turbines was done in the first half of the 1800s by James Francis, Jearum Atkins, and Lester Pelton, among others. In 1882, the first central hydroelectric generating plant was built in Appleton, Wisconsin - powering 250 electric lights.[2] Though literally thousands of small hydropower sites were closed down in the following 100 years, the U.S. currently gets 66,817 MW of electricity from its plants. In 1977, this amounted to 12% of U.S. requirements for electricity. In the mid-1930s, hydroelectric power provided about 30% of total requirements.

Large scale hydroelectric plants have been developed in Canada and around the world. While the U.S. lost interest in small or medium sized plants, some nations of Europe, Russia, and -- most actively -- China continued their development. China now has an estimated 60,000 hydroelectric sites averaging 42 kw each. In the past two years a number of new commercially available medium and small hydroelectric systems have become available in this country, as the energy crisis has again focused attention on the potential of our small streams to produce power.

TECHNOLOGY

Most of the energy sources introduced in these pages have both mechanical and electrical applications. Some have direct thermal uses, as described in the Solar Thermal section. Some mechanical processes can also produce heat without electricity, such as using wind or hydropower to cause heat by friction.

Water has still another dimension that makes it unique among energy sources. That is its chemical combination of hydrogen and oxygen (H_2O). Hydrogen is a usable fuel, and oxygen is used in many energy conversion processes to make them more efficient. Electrolysis is a simple process which uses electricity to separate water into its chemical elements. These elements can be stored in cylinders or tanks under pressure, then recombined in a fuel cell to once again produce electricity. This double process then makes the abundant water on earth a massive storage device equivalent to a 370 billion kilowatt battery.

When electricity is being produced during times of low demand, the excess may be stored by the electrolysis of water and bottling the hydrogen or oxygen gas produced in the process. Hydropower has as its energy source the potential energy of a mass of water at a higher elevation than the use point. The vertical distance (the head) through which the water falls is the critical factor in virtually all hydropower technologies. Simply stated, the theoretical power available in moving water is the weight of the water flowing in a given time period multiplied by the drop in elevation (head - in feet or meters) of the water.(1)

The technical formula for assessing the amount of energy obtainable from a stream is

$$P_{tkw} = \frac{QHe}{11.8} = \frac{AVHe}{11.8}$$

where P_{tkw} is the theoretical power obtained from the stream in kilowatts; Q is the flow of water in cubic feet per second (ft^3/sec); A is the average cross-sectional area of the stream in square feet; V is the average velocity of the stream in feet per second; H is the head; 11.8 is the constant accounting for the density of water and the conversion from foot-pounds/second to kw; and e is the overall conversion efficiency.

The elements of a typical hydropower system include the water, any of the simple or sophisticated methods of conveying the water directly to the wheel or turbine, the wheel itself, the discharge pipes to return the water to the stream, and -- in the case of hydroelectricity -- generators and batteries.

Figure 1 is an illustration of a simple, low output hydroelectric plant. The dam retains the water, creating a pond or reservoir both to store energy and elevate the surface of the water (which increases the head, therefore, the obtainable power). In this example, the water is transported from the dam to the turbine in an open channel. In other systems, the water may be enclosed in a conduit and put under pressure through gravity. This enclosed channel is called a penstock. A trade-off must be made in the location of the actual power house; locating it further downstream permits greater head, but also increases the inefficiencies inherent in diverting the water in pipes or channels.

Hydropower systems range from crude water wheels to massive hydroelectric plants such as the Grand Coulee Project. Water wheels, which have almost become obsolete, are named for the manner in which the moving water strikes them.

Overshot wheels (Figure 2) operate in a vertical plane and are turned as water fills buckets or vanes at the top and empties at the bottom. Undershot wheels (Figures 3a and 3b) are turned by water flowing mainly in its channel. Breast wheels (Figure 4) receive the water at a height equal to the center of the wheel. The tub wheel or roue a cuve manufactured in Budapest is the only water wheel currently in production. This water wheel turns in a horizontal plane and is fed by a relatively sophisticated wooden channel or penstock.

The water turbine is the trim and streamlined water wheel of current hydroelectric technologies. Large, bulky, and much less expensive and efficient water wheels may be used for electrical generation by attaching a series of pulleys and belts to increase rotational speed sufficient for generation.(6) Durable and reliable water systems for electrical generation should, however, utilize high speed turbines. The water

HYDROPOWER

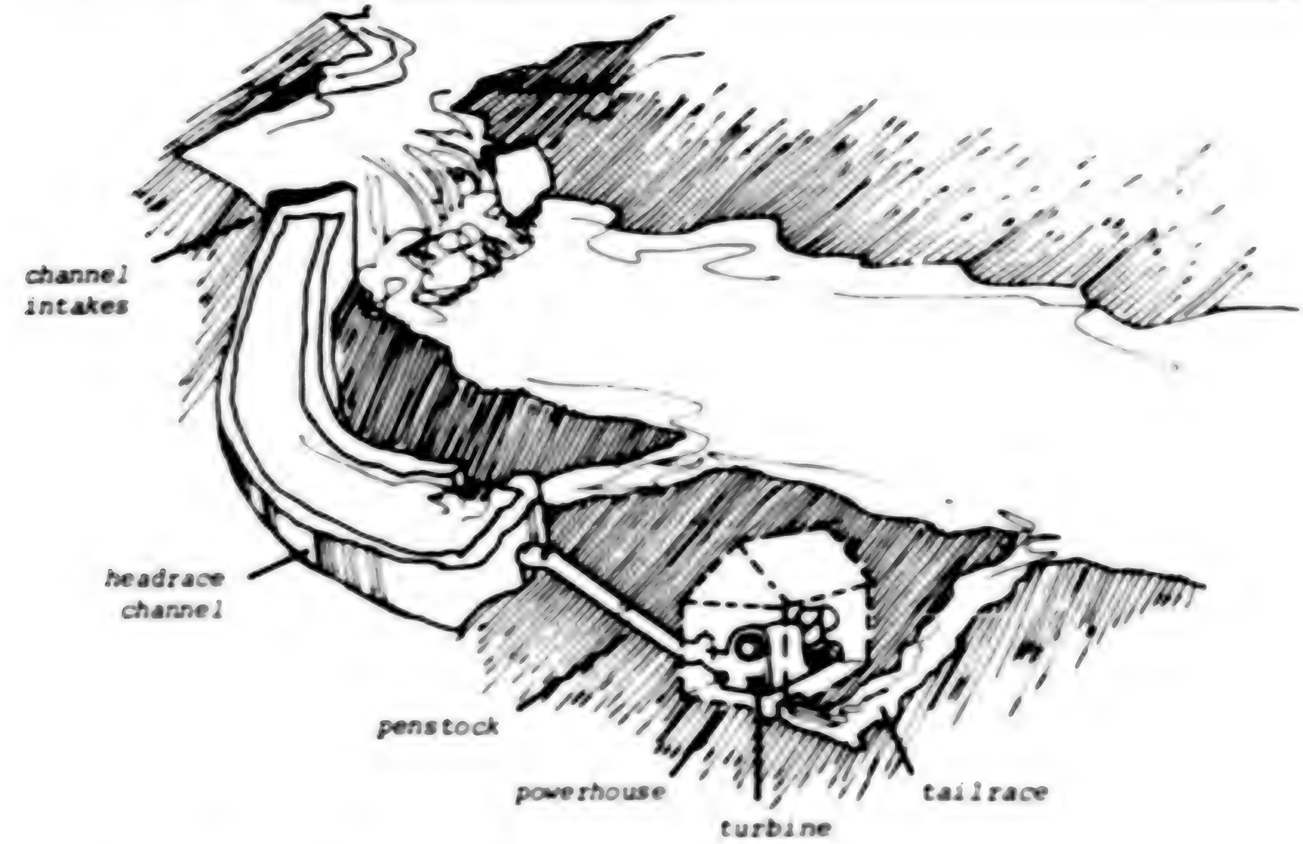


Figure 1. A Typical Installation for a Low-Output Water-Powerplant

turbine differs from the water wheel because the turbine is carefully designed so the flow of water will be steady and even through the passages created by the turbine blades. Water enters the passages smoothly and leaves with little velocity left, most of the available kinetic energy having been transmitted to the rotor. Since the water is carried to the turbine in pressure conduits instead of open channels, 80 to 90% efficiency is possible. The turbines are much better suited for coupling with electric generators because they spin at a higher speed that is more suitable to the speeds required by most electric generators.

A "run of river" plant is a power plant (usually hydroelectric), that uses the flow of the stream as it occurs and that has little or no reservoir capacity for storing water. They are also sometimes called "stream flow" plants.(2) Run of river hydroelectric plants (because there is no storage) can only be relied on for a steady output equal to the minimum annual flow, unless there is battery storage or the system is connected to the utility grid. When water storage is available, water can be released at times of peak demand to increase available power. In this way, energy output can be controlled.

There are two primary types of turbines. The two types are classified as impulse and reaction. Various models of turbines are distinguished by the names of their developers or promoters. The Pelton (Figure 5) is classified an impulse turbine, while the Francis (Figure 6), Nagler (Figure 7), and Kaplan are variations of reaction technologies.

In an impulse turbine, total energy head is converted into kinetic energy by a stationary contracting nozzle which produces a jet of water. The jet turns bucket-like structures on a runner, and

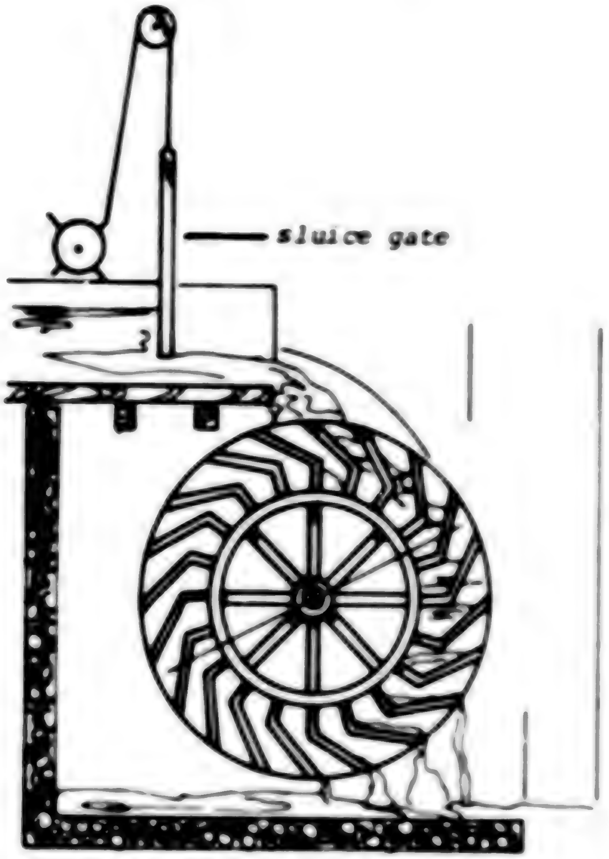


Figure 2. An Overshot Waterwheel.

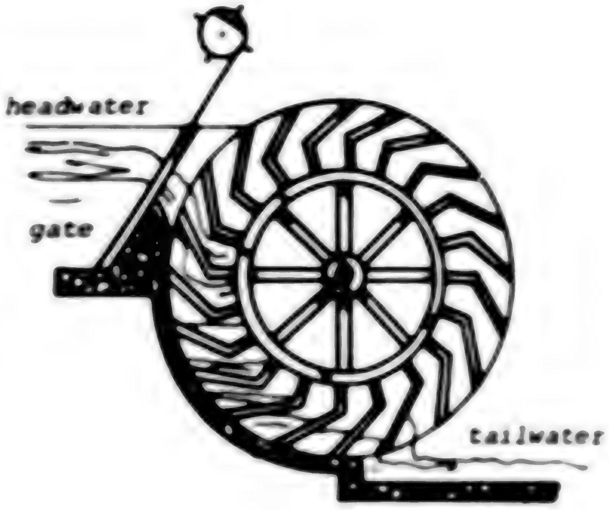


Figure 4. A Breast Wheel

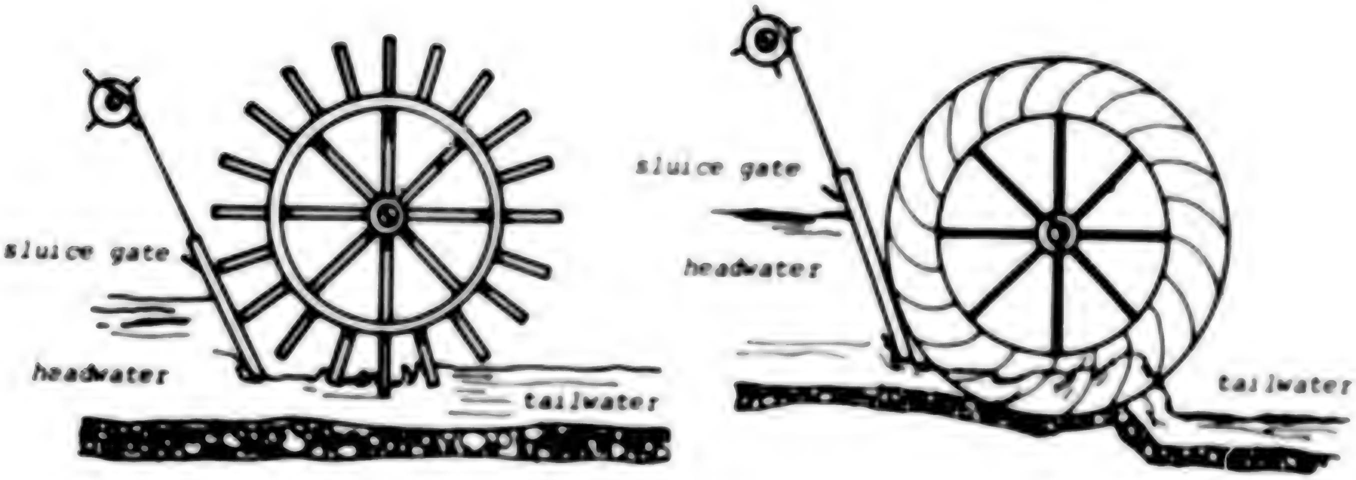


Figure 3. A Simple Undershot Wheel (a) and a Poncelet Wheel, (b), a Modification.

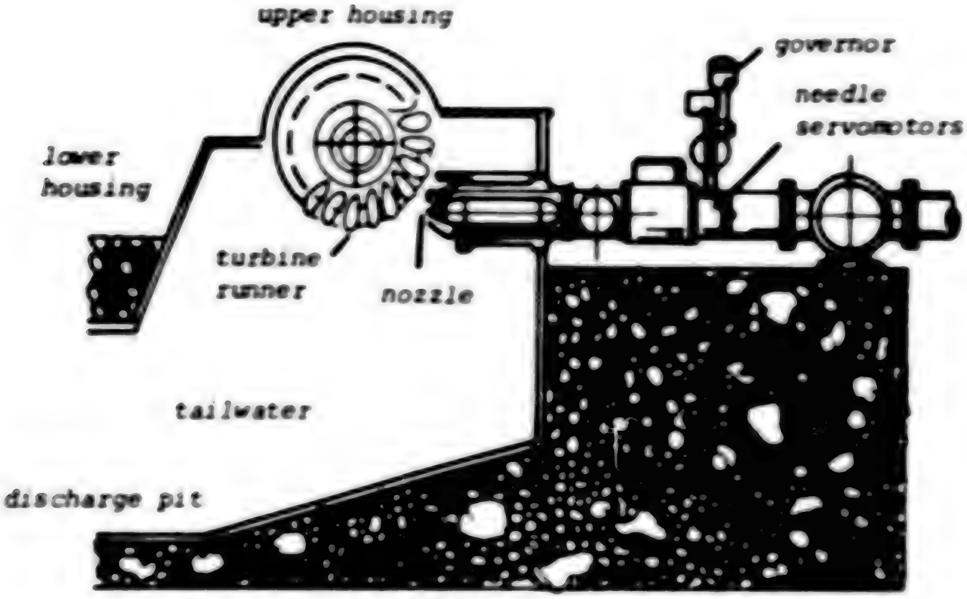


Figure 5. Typical Pelton Impulse-Type Turbine Installation

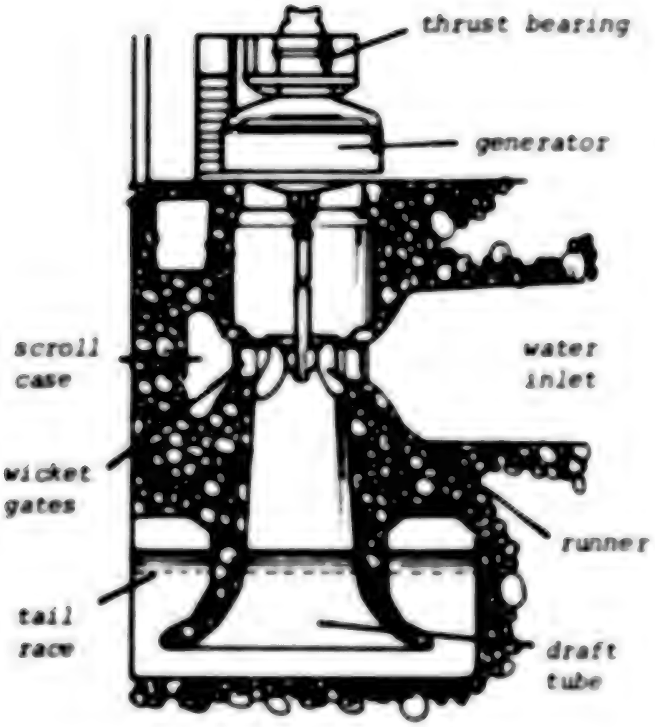


Figure 6. Cross-Section of a Francis Reaction-Type Turbine Installation

the water flows on into the tailrace. The head for a Pelton is measured from height of water surface behind the dam to the level of nozzle, since the turbine is not submerged. Smooth, bucket-shaped blades, struck at 90 degrees to the nozzle, are the most efficient.

Reaction turbines are of two types - the Francis and the vertical flow propeller types. The propeller turbines are further divided into fixed-blade (Nagler) and adjustable-blade (Kaplan) types. In reaction turbines, part of the total head is converted into kinetic energy and part remains as pressure head, which decreases as it passes through the turbine. The pressure builds due to gravity because the water flow is in a closed conduit system leading to a restrictive nozzle. Reaction turbines run submerged with a continuous column from head race to tailrace. Kaplan blades can be pivoted on their axes to either feather into the water or provide more lift during operation to compensate for power demand and head fluctuation.

A third type of turbine which is primarily for use with low head is the bulb-type (Figure 8). This type had

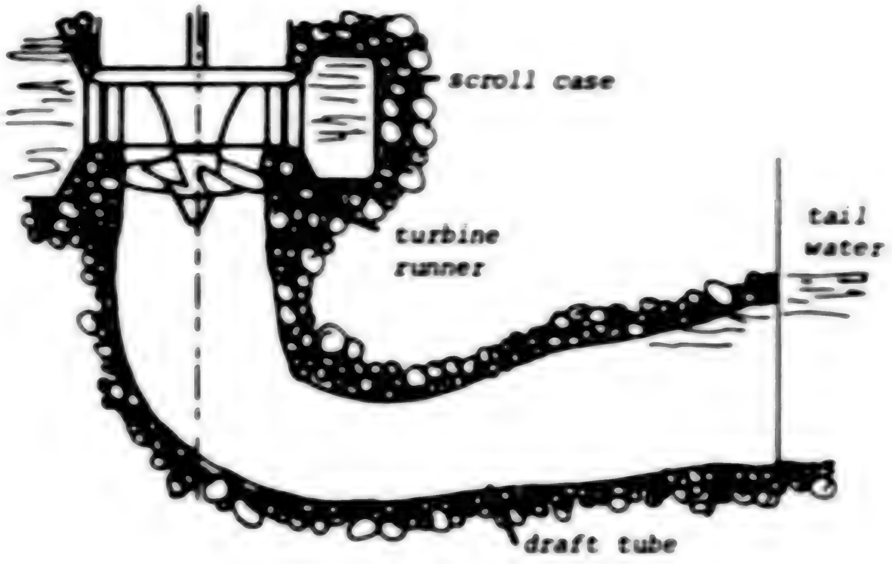


Figure 7. Fixed-Blade (Nagler) Propeller Turbine Installation

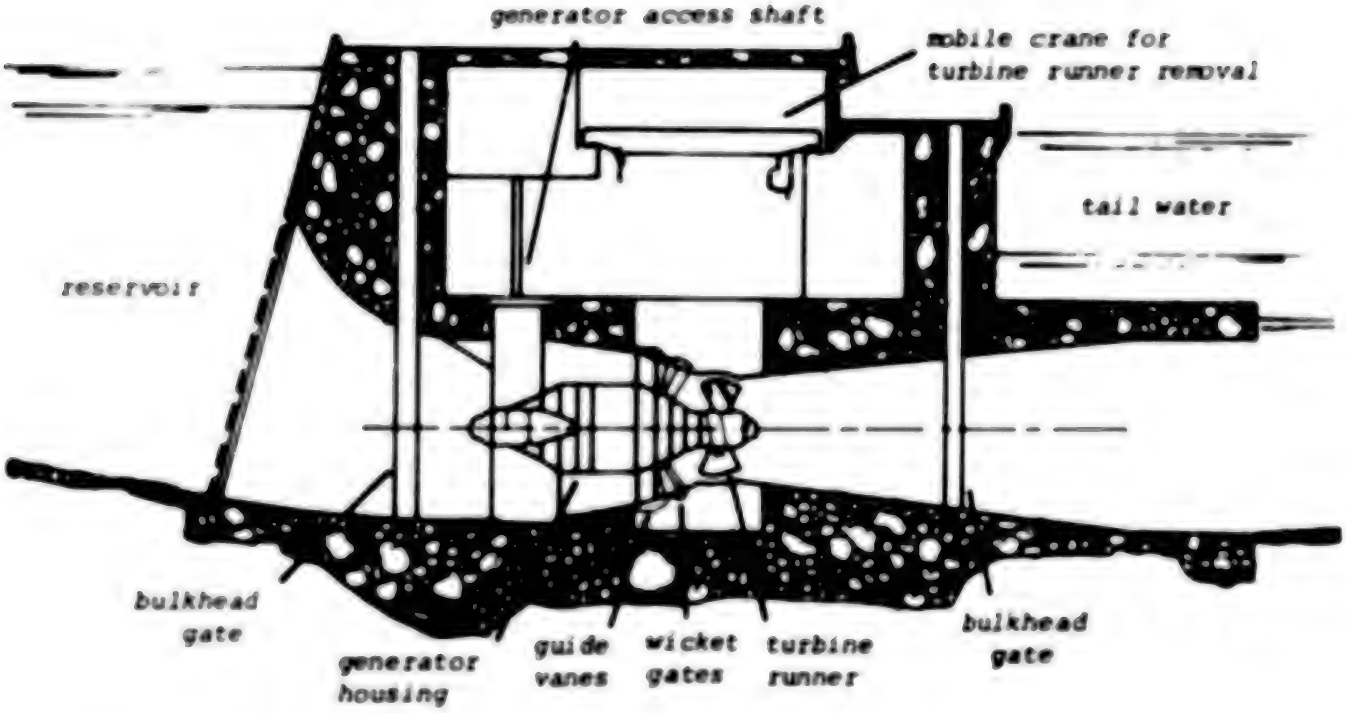


Figure 8. Bulb-Type Axial-Flow Turbine Installation

gone out of production in the U.S. but now that interest has rekindled, several companies are preparing to produce it. It is currently being tested by the U.S. Department of Energy in Idaho Falls, Idaho. It is also being used in La Rance, France, in a tidal electric plant. Another low head turbine is the Banki or Michell turbine (Figure 9), which has been built for heads of 3 feet and more. These can be built by non-technical people on-site, following the plans presented in Reference 6.) Other new technologies are also being developed for hydroelectric applications around the world.

Choice of turbine in a particular installation is normally directly dependent on head. Generally, Pelton units are preferred for high-head service (1,000 to 5,800 ft.), Francis units for medium heads (200 to 2,205 ft.), and propeller or Kaplan units for low heads (50 to 289 ft.)(2)

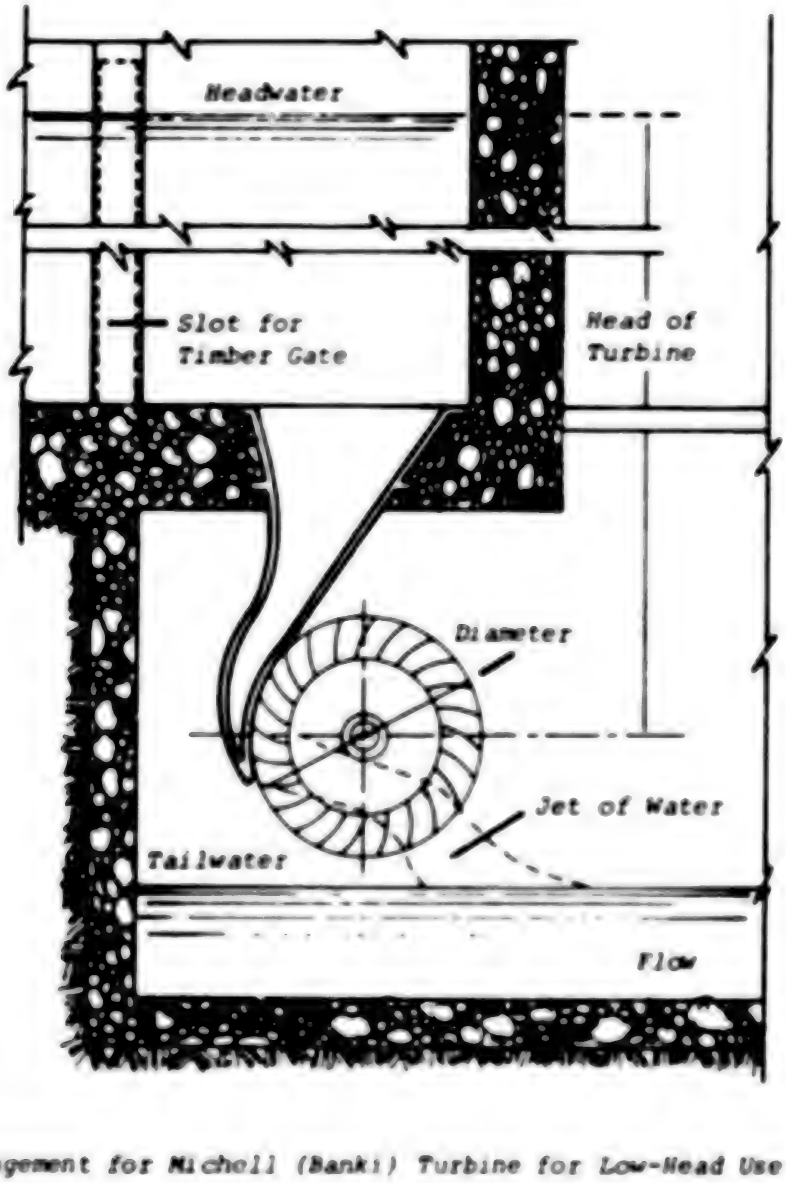


Figure 9. Arrangement for Micholl (Banki) Turbine for Low-Head Use Without Control

HYDROPOWER

The current interest in low head hydroelectric technology stems from the fact that most large scale sites have already been used and from an inclination towards decentralized, renewable energy systems. Of the hydropower technologies, hydroelectric is the most efficient at present. There is very little use of hydropower in mechanical applications even though it is entirely feasible. Like wind electric systems, hydroelectric systems cover a wide range of output capabilities, and can generate either direct or alternating current (DC or AC) that can be stored in a number of ways. Furthermore, electricity is the most versatile form of energy and can be stored in primary storage systems (batteries) as well as in such secondary storage systems as electrolysis and pumped water storage.

DC electricity requires a separate set of transmission lines from those carrying AC, and appliances must either be adapted or new DC appliances purchased to operate on the DC voltages. DC cannot be transmitted over great distances and must have separate storage if a continuous supply is unavailable. The interface of DC systems with a utility grid is possible only after inverting to AC.

In remote locations, hydroelectricity can be stored in batteries or in a reservoir with control over the flow of water. No storage is required (even in remote locations) where a run-of-river hydroelectric system provides an adequate and continuous power output. Economic analyses show that in many instances it is less expensive to develop local sources of energy for remote locations than to tap the nearest electric grid. These local sources are also often very competitive with the individual fossil fueled generators normally considered, and which require frequent fueling and maintenance.

The most effective form of storage for sites already connected to the utility grid is a direct interface from the hydroelectric system to the existing grid. (See section on Storage and Grid Integration.) When the production of electricity from the hydroelectric system is greater than the needs of the site, the DC may be inverted to AC and fed into the grid. When the site's needs are greater than the hydroelectric system can produce, additional electricity can be drawn from the grid system to provide supplemental power.

ADVANTAGES / DISADVANTAGES

Advantages

The potential energy in water at an elevation above sea level is one of the purest forms available. For those parks, refuges, and hatcheries that have running water and/or lakes, the use of hydropower offers many advantages. Hydropower's advantages are that it is: 1) almost pollution free (except where contaminated before use); 2) power without waste residuals; 3) relatively easy to control; 4) high efficiency (80 to 90% of the controlled water energy can usually be converted to useful work); and 5) in the form of pumped storage is in many cases a practical means for storing large amounts of excess electric power for use at later times.

Compared to other "clean" energy forms, such as wind or solar energy, a steady supply of energy from water is relatively easy to produce. In fact, the techniques for building dams to raise the effective height of the water, and sluice gates and canals (or penstocks) to regulate the flow, are well known. These methods for controlling water to produce hydropower are simple compared to trying to manipulate either the wind or sunshine to produce a steady uninterrupted flow of energy.

Disadvantages

However, harnessing water power has disadvantages that must be considered. These include: 1) initial costs may be relatively high; 2) damming streams can present ecological problems; 3) ownership of water rights can be a controversial issue, with serious legal implications; and 4) misconceptions still exist regarding the scale and availability of remaining hydropower resources. For example, one energy expert has said that most of the feasible hydropower sites in the U.S. have been developed. This is true for large scale sites, but neglects the tens of thousands of small and medium scale sites.

A critical misconception of researchers and decision makers is that hydropower utilizes a thoroughly mature set of technologies that need no further research. Until very recently, little federal funding has been available for research and development. Some government monies are now provided for the design of smaller scale hydroelectric systems as well as for research into the social and environmental effects of hydropower systems.

Unlike wind, hydropower technologies have never been forgotten or disregarded. Hydropower at the present time is not more widely used for both mechanical and electrical applications in the U.S. due to environmental considerations and matters of scale. Studies have shown that dams cause: 1) significant disruptions to local flora and fauna; 2) increased nitrogen in slowed waters that is unhealthy for fish; 3) flooding of valuable crop lands; and 4) alterations in the use of downstream water. Environmental impacts exist for every scale of hydropower applications where dams are used or the entire flow is otherwise disrupted. Impacts are normally a function of scale and are smaller at the smaller scale sites. Technologies that divert a portion of a river or stream are much less disruptive.

APPLICATIONS

Commercial units for hydroelectric production may be more reliable than do-it-yourself systems built by park, refuge, or hatchery personnel. However, the construction of a simple wheel to power a pump, mill, or some other mechanical process can be an invaluable educational tool as well as useful energy source. Plants and homeowner kits for such a project are available through sources listed in References (1) and (5).

Except for unusual conditions where a large river or stream may provide adequate electricity to meet all the needs of a park, refuge, or hatchery, hydropower applications would be supplemental to existing sources. Water can be stored in a lake or pond and controlled by the conduit or channel size, sluice gates, or adjustable nozzles. This control permits a more predictable and steady power output.

Electrical Applications

The energy output is more usable when converted to electricity and used for the following applications:

1. Direct grid subsidy -- using DC or AC generation to make the hydroelectric system essentially a "negative appliance" which reduces electrical demand from the grid.
2. Battery storage systems -- for remote applications where grid interface is not possible.
3. Charge batteries for electrical vehicles.
4. Inversion to AC to subsidize general electrical requirements. These requirements may include powering lights, appliances, communications equipment, and machinery.

Electricity produced locally may be used to charge batteries for electric vehicles, or sold to concessionaires or the local utility if production outstrips demand. Hydroelectricity can power pumps to irrigate dry land for better crop production. In addition, the electricity from low output generators can be used to run motors in sewage processing plants or devices to stir stagnant water for aquaculture.

Mechanical Applications

Mechanical applications may also be considered in the interest of saving electricity from other sources. These include:

1. Milling, either for grinding, grain or cutting wood. Milling is the best proven of the mechanical applications.

2. Because water can be controlled so that its power output is predictable, hydropower can be directly used for such mechanical purposes as driving small industrial tools.
3. Water pumping and ciculation is feasible for domestic uses or for irrigation, land reclamation, and fishery applications.
4. Compressing air for industrial or agricultural applications.

Review

In reviewing the above applications, care must be taken to:

1. be certain demand has already been reduced to its absolute minimum. The least expensive form of new energy is that made available through increased efficiency and conservation.
2. be certain that anticipated consumption increases are included in planning. Addition of new facilities or increasing the use of existing ones may cause an increase in demand for services and hence for energy. This should be anticipated in the planning process.

If you plan to utilize the general grid subsidy alternative, you need only to know your total amount of electrical demand (see section on Storage and Grid Integration). However, if you plan to use hydropower for a specific electrical purpose use Tables 1 and 2 in Appendix B to compute the size system required.

The remainder of this discussion will focus on electrical applications. If current or projected energy consumption at your park, refuge, or hatchery can be met in part by mechanical hydropower processes, check with manufacturers listed in the References.

F. REQUIRED ENVIRONMENTAL CONDITIONS

Environmental conditions required for producing hydropower at your site include the following:

1. A river, running stream, an elevated lake or storage tank.
2. An area reached by running water where the following items can be installed without adversely affecting the park, refuge, or hatchery:
   a. Equipment to convey water to the turbine or water wheel, such as a canal or penstock and the necessary sluice gates or pipe fittings and valves.
   b. The turbine or water wheel and their discharge piping or draft tubes.
   c. An electrical generator.
   d. Any indirect connection between the turbine or water wheel and generator, such as belts or gears.
3. Access for transmission lines between the generator and the point of use or connection to the electric grid.

PRODUCTION POTENTIAL

Assessment

If a review of possible hydroelectric applications and an examination of current and projected electrical needs suggest that you should pursue the potential at your site, begin here. You must know and use several general criteria, but any decision will ultimately be based on site-specific observations.

For example, the Army Corps of Engineers has identified 47,000 existing dams in the U.S. which could accommodate hydroelectric plants. Your park, refuge, or hatchery may contain one of these identified sites, and its production potential may already have been calculated. You should check with your local Army Corps of Engineers' office before taking further steps. Also, check for survey and any other records that may be available through the Department of Interior, the local electric company, and the local land office.

To determine the power potential at your site, consider the following factors:

1. Power available is directly dependent on how far the water falls, called the head of the stream or river.

2. Power available is also related to the amount and velocity of the water in the stream, called flow, or usable flow.
3. Finally, the availability of water on an annual basis is important for sizing a unit. Streams that are dry much of the time are rarely good locations for hydropower facilities. Do not consider reservoirs, rivers, streams, or springs that are dry more than an occasional day or week in the course of a year.

Other general information may be gathered from local electric companies which are familiar with the region, though not necessarily with your site. If you have no idea whether or not a suitable hydropower site exists on your park, refuge, or hatchery, large scale topographical maps of the area may be helpful.

Once you have addressed the specific factors related to your electrical demand and are familiar with the general criteria for good decision-making, you should go to the potential site and take measurements.

Calculations

Calculating Head

First, check available sources to determine if the site has already been surveyed. If the check with the Corps of Engineers, Department of Interior, and local sources fails to produce survey information, and if you can afford the expense, have a surveyor measure the head. If the site has not been surveyed and you cannot afford a surveyor, you may make a simple measurement of the head yourself as shown in Figure 10. In the calculations, the correct number to use for the head is the vertical distance from where the water will enter the pipe, canal, or conduit to where it will be ejected by the turbine or water wheel.

The tools to be used for measuring head as shown in Figure 10 are a carpenter's level, a stand (tripod or sawhorse), and a measuring tape. The procedure is as follows:

1. Set the level on the stand. Make sure that the level is horizontal (level or perpendicular to gravity) and at the same elevation as the water source

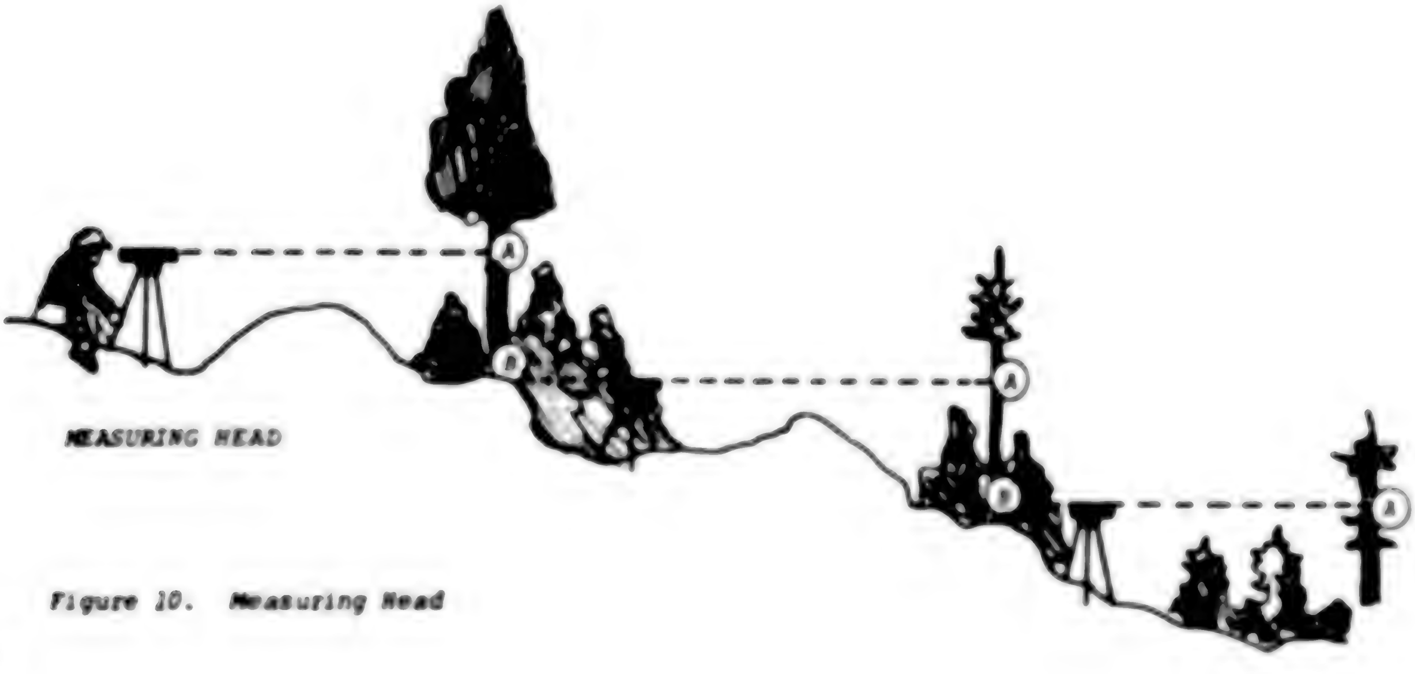


Figure 10. Measuring Head

2. Sight along the level to a spot on a nearby object which can be reached for measuring.
3. Have a partner measure the vertical distance from the point sighted (A) to the base of the object (B) and record this number.
4. Repeat this procedure until you end up at the same level as the proposed power plant site.
5. If more than one set-up was required, add the distances. The sum of these distances is the head.

Remember, you are simply taking the sum of the elevation differences from the water source to the turbine site. You need not be concerned with horizontal distances for determining head. You need not travel in a straight line. You should reset the level as close to the point B elevation as possible (sight back to check). For heads of 25 feet or less you should be as accurate as possible. In these cases, hiring a surveyor is advisable.

Calculating Flow

First, be certain the flow of the spring or stream has not already been measured. Scrapped plans or designs for a defunct system are possible sources of information. Check with people living near the stream or river. It is unlikely that flow measurements have been taken, but even estimates may help you make your calculations.

Measurements should be taken during the dry or slow season, so the minimum continuous output for the hydropower system may be calculated.

Spring or small stream flow may be calculated as follows:

1. Dam up the spring and divert its flow through a single opening.
2. Place a 5 gallon container beneath the opening and carefully count the number (n) of seconds required to fill it completely.
3. Then the flow (Q) is:

$$Q = \frac{5\ \cancel{\text{gal}} \times 0.1337\ \text{ft}^3/\cancel{\text{gal}}}{n\ \text{sec}}$$

$$= \underline{\frac{0.6685\ \text{ft}^3}{n\ \text{sec}}}$$

or

$$Q = \frac{5\ \text{gal} \times 0.1337 \times 60\ \cancel{\text{sec}}/\text{min}}{n\ \cancel{\text{sec}}}$$

$$= \underline{\frac{40\ \text{ft}^3}{n\ \text{min}}}$$

(Note: The lines drawn through the symbols for gallons (gal) and other units of measure show that they cancel).

Example: If the number (n) of seconds to fill the container is 25 seconds, then

$$Q = \frac{0.6685\ \text{ft}^3}{25\ \text{sec}} = \underline{0.02674\ \text{ft}^3/\text{sec}}$$

or

$$Q = \frac{40\ \text{ft}^3/\text{min}}{25} = \underline{1.6\ \text{ft}^3/\text{min}}$$

A fairly accurate, reasonably simple procedure for determining the flow of large streams is the following:

1. To determine the cross sectional area (A), select a uniform easily measured spot along the stream. Measure the width (W) of the stream. Use a yardstick or a longer graduated pole to measure the depth at equal intervals along the cross-section of the stream. Record the depth at each interval and take the average.

Example: Let W=10.2 ft; D_1=1.0 ft; D_2=1.5 ft; D_3=1.7 ft; and D_4=0.8 ft. The depth (D) is $\frac{1.0 + 1.5 + 1.7 + 0.8}{4}$

$= \frac{5.0}{4} = \underline{1.25\ \text{ft}}$. and $A = D \times W$

$= 1.25\ \text{ft} \times 10.2\ \text{ft} = \underline{12.75\ \text{ft}^2}$

2. To determine the stream velocity (V_s), choose a stretch of the channel which is relatively straight and free of obstacles such as sand bars or large rocks and: a) mark off two points 25 feet (d) apart; b) on opposite sides of the stream drive two stakes (see Figure 11); c) tie a line between each opposing set of stakes; and d) have someone drop a float in the middle of the stream at the upstream line, and count the number of seconds (t) it takes the float to reach the downstream line.

The equation used for calculating the stream velocity is

$$V_s = \frac{d}{t} \times 0.8$$

where d is the distance between the lines, t is the time required for the float to travel that distance, and 0.8 is a coefficient that compensates for the fact that water near the bottom does not travel as fast as the water at the surface.

Example: If d = 25 ft and t = 8 sec, then

$$V_s = \frac{25\text{ ft} \times 0.8}{8\text{ sec}} = \underline{\underline{2.5\text{ ft/sec}}}$$

or, converted to minutes,

$$V_s = \frac{(25\text{ ft})(60\text{ sec/min})(0.8)}{8\text{ sec}}$$

$$= \underline{\underline{150\text{ ft/min}}}$$

Therefore, the flow (Q) for this larger stream is

$$Q = A \times V = 12.75\text{ ft}^2 \times 2.5\text{ ft/sec}$$

$$= \underline{\underline{31.88\text{ ft}^3\text{/sec}}}$$

Usable Flow

Because only a portion of the entire stream may be used to generate electricity, the total flow must be converted to usable flow. Just how much of a year round stream may be safely diverted depends upon the character of the individ-

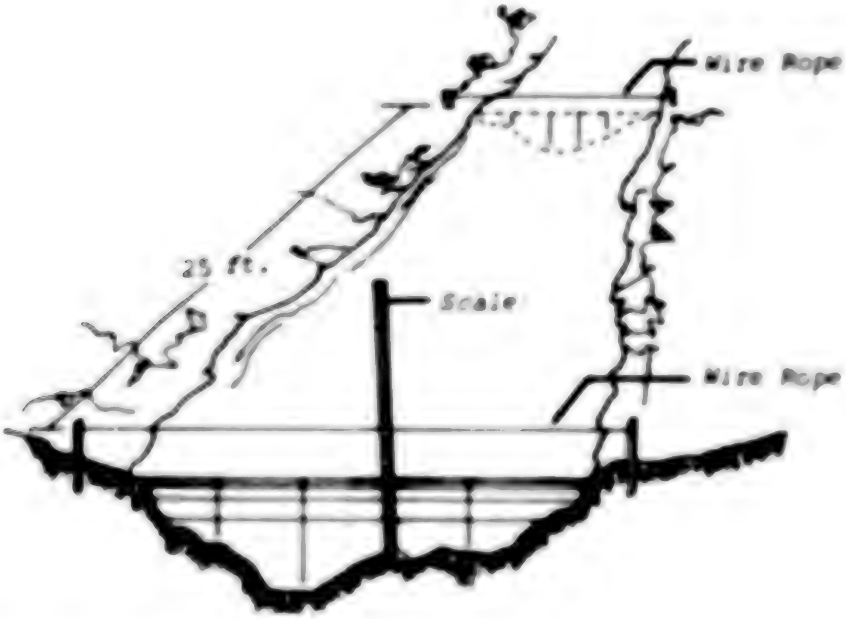


Figure 11. The Float Method of Measuring Flow

ual stream itself. As a good working figure, plan on diverting no more than 25% of the total flow during the dry season for energy development. Therefore, to compute total flow (Q) into usable flow (Q_u) multiply Q by 0.25.

Example: $Q_u = Q \times 0.25$

$= 31.88 \text{ ft}^3/\text{sec} \times 0.25$

$= \underline{7.97 \text{ ft}^3/\text{sec}}$

The most accurate calculations of flow are made by constructing a weir. A weir is built across the stream like a dam with a notch of certain dimensions cut out. (See Figure 12.) It is a somewhat difficult construction task, but is considered essential before a larger hydroelectric site is seriously considered. Once the weir is in place, measurements may be taken over time. The weir method is described in detail in Reference(7)

Power

Once the above calculations regarding the stream characteristics have been performed, the potential electrical power available at the site can be computed as follows:

The theoretical horsepower (P_{th}) available from the water is:

$$P_{th} = \frac{Q_u \times H}{8.8}$$

where Q_u is the usable flow rate in cubic feet per second (ft^3/sec), H is the head in feet, and 8.8 is the correction factor for the units.(1)

Example: With the usable flow computed above ($Q_u = 7.97 \text{ ft}^3/\text{sec}$) and a head of 25 feet, then

$$P_{th} = \frac{(7.97 \text{ ft}^3/\text{sec}) \times (25 \text{ ft})}{8.8}$$

$$= \underline{22.64 \text{ hp}}.$$

Converting theoretical horsepower into electricity in kilowatts we have

$$P_{tkw} = (22.64 \text{ hp}) \times (0.746 \text{ kw/hp})$$

$$= \underline{16.89 \text{ kw}}$$

For direct conversion to theoretical electric power, use:

$$P_{tkw} = \frac{Q \times H}{11.8}$$

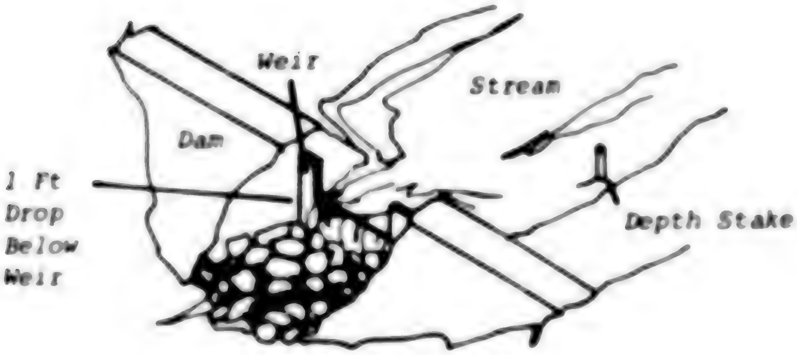


Figure 12. Weir Dam

Example:

$$P_{tkw} = \frac{(7.97\ ft^3/sec) \times (25\ ft)}{11.8}$$

$$= \underline{\underline{16.89\ kw}}$$

If the flow is measured in liters per second and the head is measured in meters, the formula for finding power in kilowatts becomes:

$$P_{tkw} = \frac{Q \times H}{101.8}$$

For example, if the head is 10 meters and the usable flow is 600 liters per second then:

$$P_{tkw} = \frac{(10m) \times (600\ li/sec)}{101.8}$$

$$= \underline{\underline{58.94\ kw}}$$

The theoretical power must be reduced by the expected losses in the proposed system. These losses include friction in pipes or channels, efficiency of the conversion system, etc. Precise measurements would be found when researching available hydroelectric systems. However, for now, you can estimate that with available technology, conversion efficiencies will be on the order of 50 to 70% of the theoretical power. For economic analyses, use 50%. If your calculations show, for example, that the minimum continuous theoretical power output of your site is 20 kw, for the purpose of economical computation you should use 10 kw.

To make a final decision on whether or not to install a hydroelectric system at your site, you must consider the following information regarding the proposed site:

1. conversion efficiencies
2. type of storage and its maximum capacity
3. rated output (maximum) of system
4. cost and payback period.

The power outputs from commercially available systems range from 0.125 kw (125 watts) to 250 kw. Most of the systems available in the U.S. are in the micro scale (0-10 kw) range. However, some manufacturers will custom build systems to any scale.

ECONOMICS

Table 1 gives some examples of various size systems that have been recently installed, or which are commercially available at the approximate price indicated. The indicated prices, however, may or may not include the cost of building a dam and/or diversion system.

Table 1 shows estimated payback periods in years for hydroelectric systems of different power outputs. Column A shows the rated power of the system; Column B gives the approximate cost to install the system at present (1978) prices; and Column C gives average output per month in kwh for each system. The figures in Column D show the cost per kwh of output over a 15-year period, based on the information in the first three columns. For example, the 2.0 kw Pelton system produces an average of 1,080 kwh/mo (Column C). Over 15 years, it will produce 1,080 kwh each month, 12 months a year, for 15 years, or:

$$(1080\ kwh/mo) \times (12\ mo/yr) \times (15\ yr)$$

$$= 194,400\ kwh.$$

Cost per kwh over the 15 year period will be

$$\frac{\$4,300}{194,400\ kwh} = \$.022/kwh$$

These figures reflect no estimate of maintenance costs for either existing or newly installed hydroelectric systems.

Columns E and F show estimated payback periods in years for these systems, given different costs per kwh of electricity from other sources. The figures in Column E have been calculated for a zero inflation rate, while those in Column F show payback with inflation in electric costs estimated at a rate of 10% per year. The figures in Column E were arrived at as follows: Usable kwh/mo (Column C) for the Pelton system are 1080 kwh/mo. Selecting a current cost/kwh of $.015, we have

(1080 kwh/mo) x ($.015/kwh) x (12 mo/yr)

= $194.40/year.

Installation of the Pelton costs $4,300. To compute simple payback period, this is divided by the first year savings:

$$\frac{\$4,300}{\$194.40} = \underline{\underline{22.11 \text{ years}}}$$

Accordingly, the figure of 22.11 years is found under the column for electricty priced at $.015/kwh. Payback on the same system at the same price per kwh, but given an annual inflation rate of 10%, will be 12.2 years - a little more than half the time estimated using a zero inflation rate. (Formulae explaining the estimation of costs with 10% inflation may be found in Appendix C.)

If funds are available to install a hydroelectric system, the figures in Table 1 show that an inflation rate of 10%, which is close to that actually being experienced at the present time, has a significant effect on the length of the payback period. This is especially true for the smaller systems. Final economic decisions should take into account the likelihood of continued price rises for electricity generated by the use of fossil and nuclear fuel.

ACTION REQUIRED

Once you have determined that there is a potential hydroelectric site at your park, refuge, or hatchery, and the amount of usable flow available, then the following steps should be taken:

1. Determine water use rights.
2. Determine the environmental impact on the surrounding and immediate area.
3. Determine if: a tie-in to the local electric grid is more advantageous; the new system can handle all your electrical needs; only a certain remote section of the park, refuge, or hatchery can best be powered by the new system; or if a battery storage system is required.

Again, if a remote section of the park, refuge, or hatchery is to be powered by the hydroelectric system, then use Tables 1 and 2 in Appendix B to determine the power requirements.

Table 1.

Estimated Payback Periods in Years for Hydroelectric Systems of Different Power Outputs

RATED POWER (Max in kw) (A)	APPROXIMATE COST (Inst) (B) ($)	USABLE kwh/mo (C)	COST/kwh OVER 15 yrs (D) ($)	(E) PAYBACK PERIOD (yrs) w/current $/kwh (no infl)					(F) PAYBACK PERIOD (yrs) w/incr $/kwh (10% infl)				
				0.015	0.03	0.04	0.06	0.10	0.015	0.03	0.04	0.06	0.10
0.5	4000	270	0.082	82.3	41.2	30.9	20.6	12.3	23.3	17.1	14.8	11.7	8.6
2.0 (Pelton)	4300	1080	0.022	22.1	11.1	8.3	5.5	3.3	12.2	7.8	6.3	4.6	3.0
5.0 (Cross flow low head)	8500	2700	0.017	17.5	8.7	6.6	4.4	2.6	10.6	6.6	5.3	3.8	2.2
12.0 (Pelton)	9000	3600	0.013	13.9	6.9	5.2	3.5	2.1	9.1	5.5	4.4	3.1	2.0
18.0 (Turgo)	16000	7200	0.012	12.3	6.2	4.6	3.1	1.9	8.4	5.0	4.0	2.8	1.8
25.0 (Turgo)	22200	10080	0.012	12.2	6.1	4.6	3.1	1.8	8.4	5.0	4.0	2.8	1.8
40.0 (Banki)	28000	12240	0.012	12.7	6.4	4.8	3.2	1.9	8.6	5.2	4.1	2.9	1.8
250.0 (Cross flow)	113000	100000	0.006	6.3	3.1	2.4	1.6	11.3 mo.	5.1	2.9	2.2	1.5	11.3 mo.

HYDROPOWER

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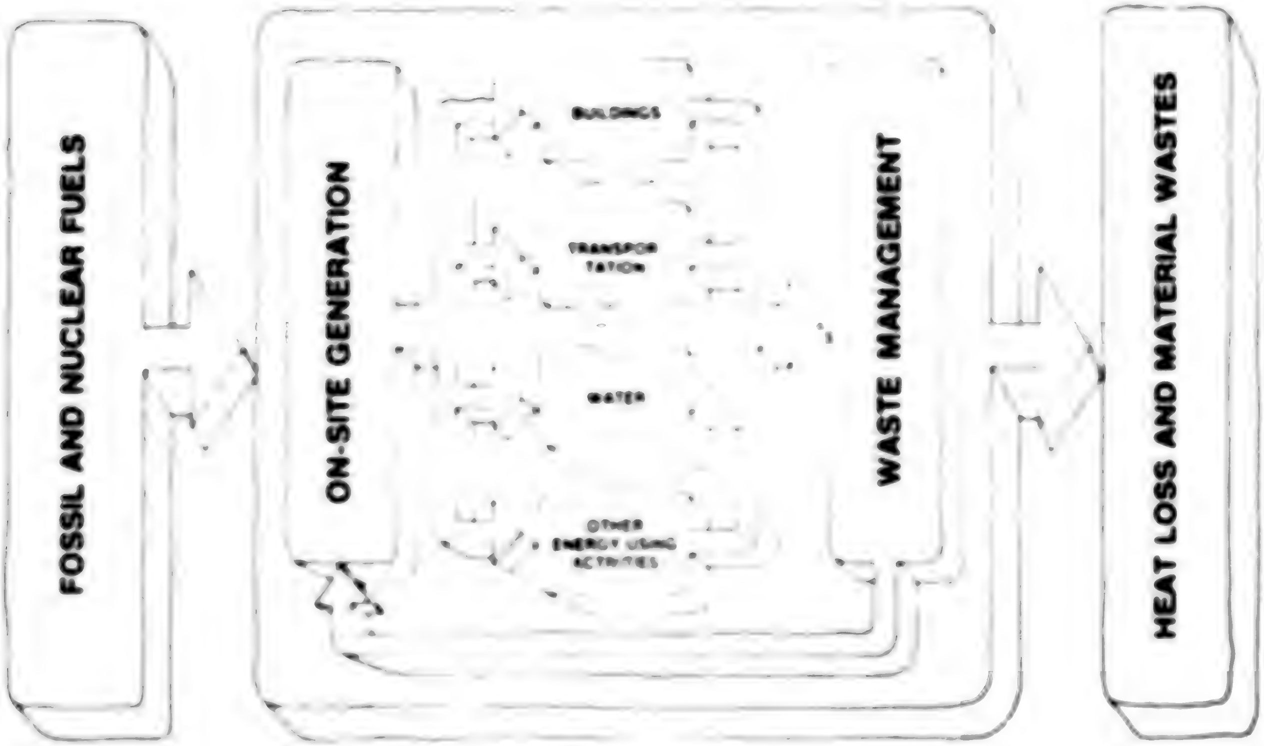
Note. Hydraulic rams, see References (1), (5), and (8).

Solar Thermal

SITE ENERGY-USING FUNCTIONS



SOLAR THERMAL

> *Our particular star is thought to have originated between eight and ten billion years ago and its present rate of output, approximately 3.8 x 10^{23} kilowatts, is caused by the conversion of mass into energy at the rate of some 4.7 million tons per second.*
>
> *It is expected to continue to emit radiant energy at this rate for another four billion years, so, for all practical purposes it is the only perpetually renewable source of energy which the planet Earth possesses.*
>
> *John I. Yellott*
> *Energy Primer*

INTRODUCTION

In one sense, solar energy is the only source of energy we have, on-site or not. The energy derived from fossil fuels, wind, hydropower, or from digestion of plant matter can all be traced back to the powerful center of the solar system. Although the solar energy reflected by clouds is mostly lost to our use, the energy absorbed by lower levels of the atmosphere warms the air and causes temperature differentials which generate winds (see Section I, Wind). The solar energy that plants absorb may potentially be converted into food energy or other forms of usable energy, such as fuel generation (see Section V, Biomass). Solar energy absorbed by the oceans causes water to evaporate and starts the hydrological conversion cycle (see Section II, Hydropower). Plant absorption also produces combustible materials such as trees and brush and, after long-term decay and geological change, the fossil fuels.

Respect for and fascination with the sun are at least as old as man's recorded history. Its awesome power and abundance have made it the center of religions and cultures, and the center of attention for tinkerers and designers interested in directly tapping its energy for man's uses. The sun is now the center of attention in energy research and development in government and in a rapidly growing solar industry, by some measures the fastest growing industry in the U.S. today.

There are three primary processes through which solar radiation is used: solar chemical, solar electric, and solar thermal. The chemical processes are probably the most important for human advantage, because photosynthesis (a chemical process) allows certain solar radiation wavelengths to cause carbon dioxide and water to unite with soil nutrients to create the plants and oxygen that sustain animal life. So far, man has made little direct use of these chemical processes except in photography. Solar electric devices are man-made, since nothing in nature has yet been discovered that converts solar radiation directly into electricity (this process is discussed further in Section VII, Photovoltaics). Solar thermal processes convert the sun's radiation, or insolation, into heat. Though the principles of capturing the sun's rays, storing it, and using it to support animal needs are apparent in nature, human devices have been designed and refined to allow the controlled use of solar thermal processes. The active processes that permit hot water and space heating, for example, are the subjects of this section.

HISTORY

The basic concepts of solar energy have been known and used for thousands of years. Focusing mirrors were used to start solar fires over 2,500 years ago -- fires for cooking, making sacrifices, and destroying an enemy's fleet of ships. For millenia, the sun has been used as the primary source for heat, illumination, plant nourishment, and the measurement of time. Since about 100 years ago, the sun's rays have been tapped purposefully and directly for such uses as distillation, low temperature hot water heating, and steam generation. Printing presses driven by solar radiation and water pumps powered by steam were running in the late 19th and early 20th century. In less severe climates where water rarely freezes, inexpensive solar hot water heaters have been commonplace for decades. Interest in solar technologies has intensified from time to time, depending on fluctuations in the availability, use, and costs of competing energy sources such as coal, oil, natural gas, and electricity. The most recent increases in fossil and nuclear fuel prices have spurred growing interest in direct solar technologies like never before. Funds spent on research, production, and advertisement by public agencies and private companies have increased dramatically in the past five years. Government expenditures on solar research and development are still outstripped by its support of fossil and nuclear technologies, but the gap is slowly closing.

Many older solar technologies have been refined and the principles of solar thermal processes have been applied to new and promising systems of capture, storage, and use. The numbers applied to the vast potential of solar energy systems to meet the needs of mankind are virtually unimaginable: the solar energy received at the earth's surface in one day is more than a thousand times the amount used by the entire human population in that same time frame. Efforts to capture even a fraction of that energy are only expected to continue and increase.

TECHNOLOGY

Solar thermal technologies fall into two broad categories, active and passive systems. Those that use few motors, chemicals, or energy-intensive hardware are called passive solar technologies. Examples of these are attached greenhouses used to supplement the heating requirements of a building and plain south-facing windows which permit the sun's radiation to enter a building during a winter day but prevent the radiation's entrance on summer days by an awning or overhang. More information on passive solar technology is included in the Buildings section of the *Planbook*. In many cases, passive solar technologies are as cost effective as conservation and retrofit practices and should be considered in any plan for solar energy investment.

The solar thermal systems discussed in this section are active solar systems. That is, they require certain "hardware" to collect and store solar energy, to automatically call for backup heat or hot water when sunshine is inadequate, and otherwise to increase the efficiency of the processes of solar energy use. Active solar thermal technologies require initial capital investment that is normally higher than conventional space and water heating technologies, but they run fuel-free for the life of the system and in many locations are economically competitive.

The two primary uses of solar thermal energy systems are for water heating and space heating. Solar hot water heating processes range from the domestic hot water systems that are the most widely used and marketed to very high temperature solar steam generators used for electrical production. In between are industrial and commercial process solar hot water systems. Space heating systems are currently extremely expensive and difficult to justify in net energy terms for most retrofit applications. Buildings designed for solar space heating -- with strong conservation built in -- offer the best applications of space heating.

The basic function of an active solar thermal system for space and/or hot water heating is to collect and convert solar radiation into usable energy. In general, active solar systems accomplish this in the following fashion: solar radiation is absorbed by a solar *collector* and placed in *storage*. Heat moves by a means of a *transfer medium* through *heat exchangers*, if more than one medium is used. Automatic or manual *controls* regulate the

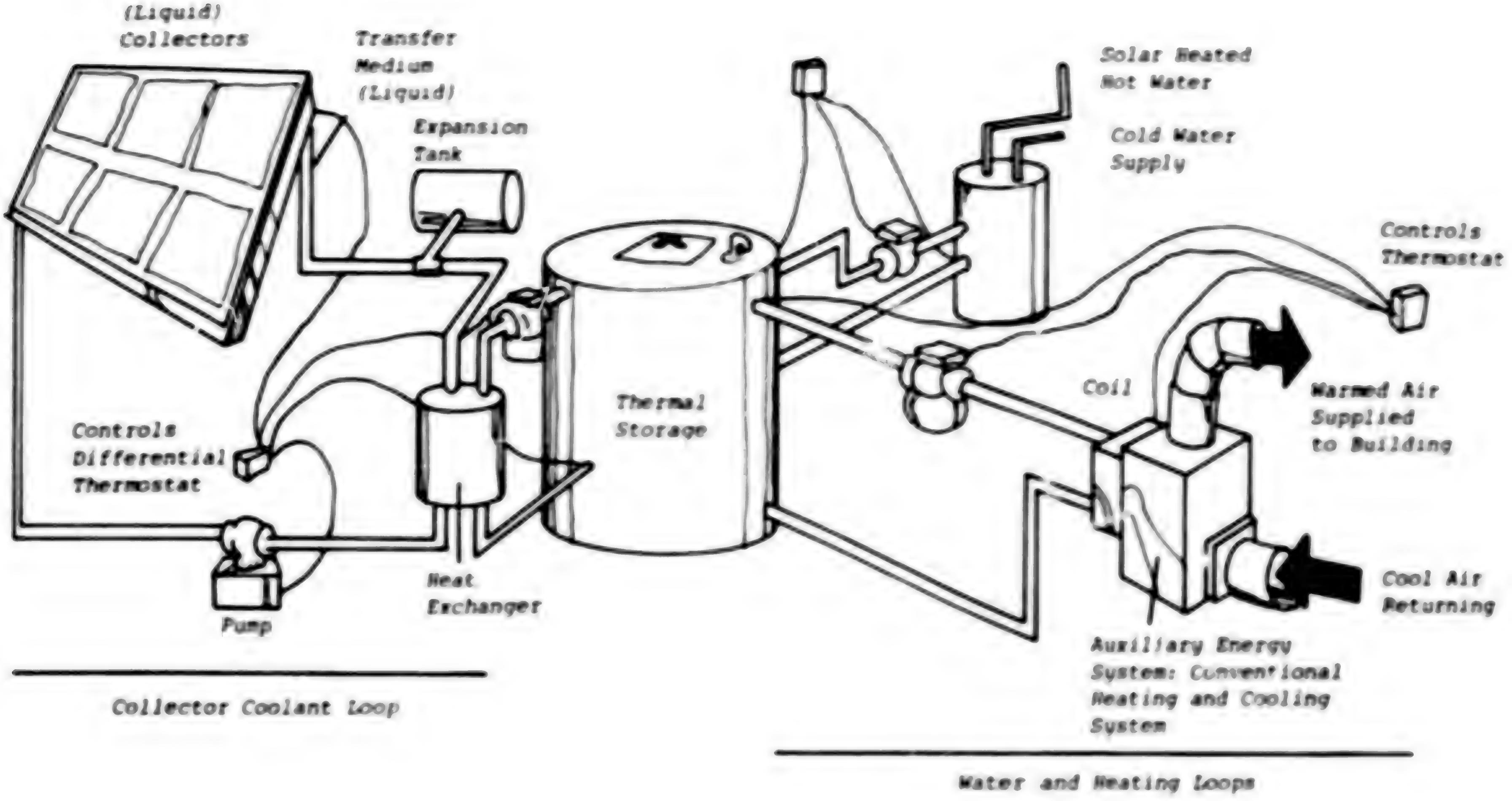


Figure 1. A Typical Active Solar System for Hot Water and Space Heating

performance of each step, stopping or starting pumps, fans, or valves. An *auxiliary energy system* is usually provided to supplement solar output and to back up the solar system, if and when it should fail. These elements or components of active solar systems may be arranged in many combinations in order to increase performance or accommodate to site characteristics and architectural requirements. Figure 1 is an illustration of how the parts might be put together in a typical application. This system would provide both hot water and space heating for a building.

The following discussion will introduce you more fully to the different parts of active solar systems.

Collectors

Two principal types of collectors are now being manufactured, the flat-plate type and the concentrating collector. Flat-plate collectors are most widely used for applications such as hot water and space heating, where working temperatures may be less than 180 degrees F. Where higher temperatures are required, advanced flat-plate systems or concentrating collectors must be used. Concentrating collectors increase the amount of heat on the collector surface through the use of hourly, daily, and annual shifts in the sun's position, they must be able to follow the sun's movement across the sky.

There are many variations of flat-plate collectors now being manufactured. The basic design is shown in Figure 2. An absorber plate, normally of black painted metal, increases absorption of the sun's energy. It is insulated to prevent heat loss. Heat is drawn off through passages for the heat transfer medium. A cover plate -- usually made of glass or plastic film -- reduces the loss of energy through reradiation to the sky.

Heat Transfer Medium

Heat transfer fluids now in use include air, water, and mixtures of water and ethylene glycol (antifreeze) and propylene glycol. Each has its desirable properties and its potential problems. Although air systems give a temperature rise of 60-90 degrees F (higher than liquid systems), air does not have high specific heat or thermal conductivity. Water freezes at a

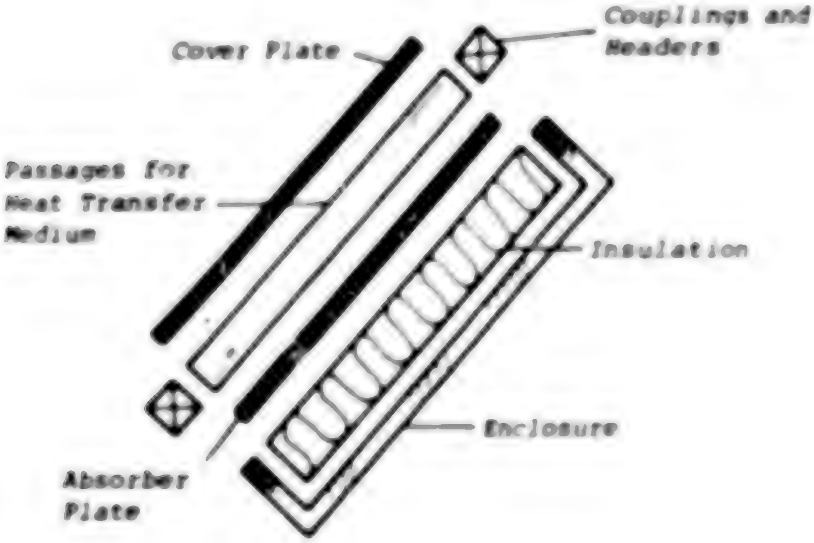


Figure 2. Functional Parts of Solar Flat-Plate Collectors

relatively high temperature and boils at a relatively low one. This problem can be solved by adding antifreeze, but glycol solutions will break down into glycolic acid at high temperatures, and in hot water systems create a need for heat exchangers between the collector coolant loop and the water storage loop (see Figure 1). Since antifreeze is toxic, a leak could contaminate the drinking water supply.

Water and water-mixed fluids also require protection against corrosion, a potentially serious problem. The viscosity, specific heat, and coefficient of expansion of transfer fluids are all important in assessing the thermal capacity of the system. Variations can have a major effect on the efficiency of a large system.

Pumps and Valves

Pumps move the transfer fluid through the system. Since they use electricity, they should be correctly sized, so that total energy savings from the solar system are not reduced by installing units that are too large. Valves are used for simple functions such as balancing the flow rate in the system or permitting drainage.

Heat Exchangers

Heat exchangers transfer thermal energy from one medium to another. In solar systems, heat transfer may be needed between the medium used in the collector coolant loop and the storage medium, or between the storage and distribution medium. Automobile radiators are typical heat exchangers. Heat from the engine is transferred through the medium of water to the surrounding atmosphere. Solar air systems used for space heating don't require heat exchangers, since heated air is blown directly into the occupied space. When a nontoxic liquid transfer medium is used in the collector coolant loop, a shell and tube exchanger can be used. Tubes for domestic hot water, or water used for heat storage or space conditioning are run through a shell that holds the liquid heated by the solar collector. If, however, ethylene glycol or another toxic substance is connected to the drinking water supply, a double wall is needed to protect against leakage that can occur if a tube fails. (See Figure 3.) In an exchanger of this type, insulation is required to cut heat loss.

Storage and Auxiliary Energy Systems

Next to the collectors, storage is generally considered the second most important element of a solar system, since it must provide heat at night and on days when collection of solar energy cannot occur. Although different types of salts have been tested, the two most popular and widely used mediums for storage are water held in tanks and rocks held in rock beds. Many variations are possible within these two types.

Typical rock bins used with air systems are filled with small stones 2 to 3 inches in diameter. Since hundreds of tons of these stones may be needed to provide a unit of the correct size, placement can be a problem. Thermal stratification occurs quickly in rock bins, which helps in designing air systems for maximum efficiency.

Tanks used for water storage range widely in cost and quality. Pressurized tanks stamped by the American Society of Mechanical Engineers and used in pressurized systems cost $5,000 to $6,000 for 2,000 gallons of capacity, while concrete tanks and precast septic tanks may cost as little as $500 to $800.

Design of the storage unit must take a number of factors into account. First, heat tends to rise, creating thermal stratification within the unit. This can be used to improve overall efficiency, if cold air or liquid connections are located at the bottom and hot connections are located where the storage tends to be hot -- at the top. Second, provision must be made for expansion. Temperatures in the system

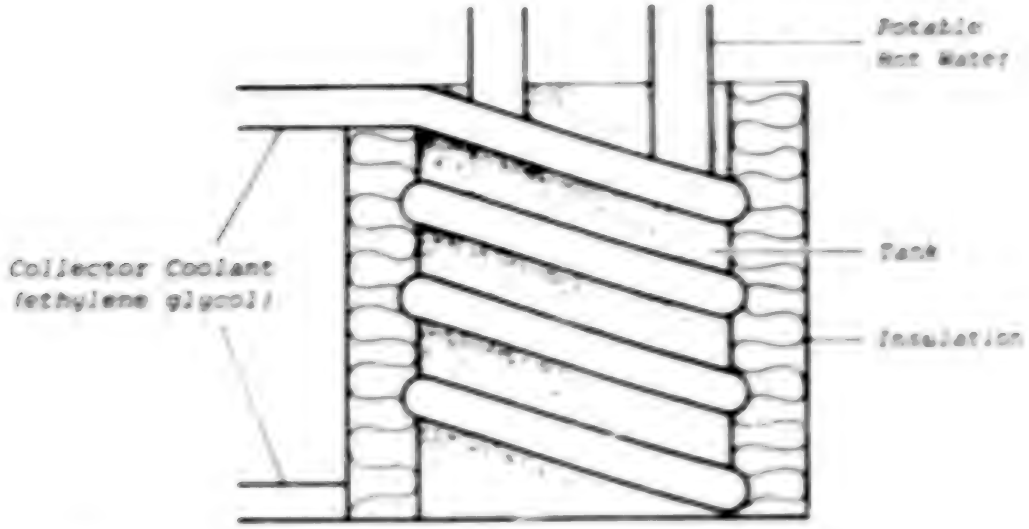


Figure 3. Double Wall Heat Exchanger

can range between 32 and 210 degrees F, and expansion of the heat transfer medium can cause problems. Installation of expansion tanks (see Figure 1) on the suction side of the pump help to minimize difficulties, but may have to be sized differently than similar expansion tanks in conventional systems. Third, storage systems should be well insulated to avoid heat loss and to prevent overheating of nearby spaces. Finally, where possible, storage should be located near the center of the building. This may not be possible if the unit is a large rock bin, or if the space in that part of the building must be used differently.

When stored energy has been depleted, an auxiliary energy system powered by conventional fuels is required.

Controls

Because the temperatures fluctuate in many parts of an active solar system, a relatively sophisticated set of controls is required. Outdoor temperatures may rise and drop 30 to 40 degrees F in a day, and the temperature of the heat transfer medium can vary by as much as 200 degrees, while the solar system must provide energy to heat space inside the building to within 2 or 3 degrees of a desired temperature. The control system, connected to thermostats, pumps, valves, and heaters at the collectors, storage unit, and auxiliary heating system, must perform the sensing, evaluation, and response functions required to achieve desired performance. A simple set of controls should be capable of handling all modes of operation. One aspect of solar system controls that differs from conventional heating, ventilation, and air conditioning (HVAC) controls is the differential thermostat used to regulate flow of the heat transfer medium. The thermostat indicates when the temperature of the fluid leaving the collector exceeds the temperature leaving the storage system by a certain value (5 to 20 degrees F.), and turns on the pump or blower. If the temperature of the fluid at the collector is less than that leaving storage, energy cannot be usefully collected, and the pump or blower is shut off.

SOLAR THERMAL

ADVANTAGES/DISADVANTAGES

As experience with solar space heating and hot water systems increases, more precise information is becoming available on the advantages and disadvantages of specific aspects of the technology. For instance, in a recent HUD publication detailing early lessons learned in the HUD residential demonstration program, it is pointed out that 10% of the collector systems in the first two cycles of the program malfunctioned due to leaking, cracking, or breaking-- problems caused by poor workmanship and faulty parts. The advantages and disadvantages listed below are general. When considering installing a solar system, all aspects of the system should be thoroughly examined for technical problems specific to the application.

The advantages of solar thermal systems include:

1. It reduces dependence on rapidly depleting fossil and nuclear fuels.
2. The fuel for solar systems is free from the sun, in virtually limitless supply.
3. There are no fuel transportation costs, as with conventional fuels.
4. The growth of the solar industry has been shown to have positive effects on both employment and the U.S. economy.
5. Sizing and cost/payback procedures are now well-standardized within the industry. Information has been prepared that allows the consumer to critically evaluate solar systems and their economic benefits and costs.
6. A growing number of architecture and engineering firms and HVAC contractors are familiar with design and installation of solar systems.
7. Solar systems are compatible with conventional hardware for domestic and basic service hot water and space heating.
8. Industry standards have been developed and are becoming widely used. These include collector efficiency standards developed by ASHRAE, installation standards available from SMACNA, and standards for residential solar applications established by HUD. These allow more precise determination of technical integrity and performance.
9. An increasing number of solar systems are warranted against defects, and the warranties are increasingly comprehensive.

Additional advantages common to solar hot water systems are that:

10. They are currently competitive with conventional fuels in most parts of the U.S.
11. Installation is relatively easy, and can be performed by individuals who have not had extensive experience.
12. They can be accepted by most existing structures and conventional water heating systems, increasing potential for retrofit.

Disadvantages of solar thermal technology include:

1. There are problems with installation and workmanship in some cases.
2. There is the potential, common in new industries, for the proliferation of misleading information and inaccurate advertising. Independent advice and analysis from engineering professionals is necessary before deciding to implement a solar system.
3. They are often more expensive than conventional systems on a first-cost basis.
4. More thorough testing of materials and components is still required (synthetic-

glazings, heat transfer fluids, etc.) to evaluate performance and long-term durability.

5. Auxiliary energy systems are required, since 100% solar systems, although technically feasible, are not economically feasible in most locations.
6. Training to assure proper installation has been incomplete and inadequate.

Solar space heating systems, because of the extensive design considerations and installation requirements involved are rarely justified for retrofit. They are used in cold months only and don't perform useful functions at other times of the year.

APPLICATIONS

The applications of the solar thermal technology are as varied as the amount of money available to invest in them. Essentially, solar thermal processes can supply part or all of the energy required to heat any amount of water to any temperature. The systems can serve as the primary source of heat for any size structure or group of structures.

The most reliable and economically competitive solar thermal systems are designed to work with an auxiliary energy system that automatically insures 100% availability. The auxiliary system for retrofit applications is the existing electric, oil, natural gas, coal, or wood heating equipment. For new structures, the auxiliary system might use wind, wood, electricity, or fossil fuels.

Solar Thermal Hot Water Applications

Applications may be listed in a number of ways. The following Table 1 identifies the general uses of solar hot water systems by end-use sector: residential, commercial, agricultural/aquacultural, industrial, and others.

Table 1. End Use Application

RESIDENTIAL	*Solar hot water can meet the basic needs in homes, dormitories, camping areas, or other facilities. Dishwashing, clothes washing, bathing, and cleaning are typical domestic uses.*
COMMERCIAL	*Large users like hospitals, laundries, and concessions requiring hot water for cleaning are ideal for solar installations. Campgrounds offering hot water for latrines, laundries, and showers should consider the technology. Swimming pool heating is probably the least expensive of the active solar hot water technologies.*
AGRICULTURAL/ AQUACULTURAL	*Hot water used in greenhouses evens out temperature changes and may keep soil warmer to permit the growing of a wider selection of plants. On dairy farms, hot water is used in cleaning milkers, parlors, and milk rooms. Solar applications have been used to provide for these needs all over the world.*
TRANSPORATION	*Solar hot water systems may be used when vehicles require constant cleaning.*
OTHER	*Specific applications of solar hot water heating may be identified in the course of reviewing current and projected energy use at a particular site. Ponds may be warmed, cooking water preheated, and animal cages cleaned. The need for hot water depends, of course, on the activities at your facility.*

Applications may also be divided into low, medium, and high temperature applications. Low temperature uses would be those where well or city water temperatures are raised to 90 or 100 degrees F. Agricultural and aquacultural uses lead this list. For example, warm water is used to facilitate incubation or lengthen a growing season. Low temperature applications are best met by low cost flat plate collector systems, or unglazed collector systems such as those discussed in Reference (1). Applications in this category include swimming pool heaters, outside showers, or others not requiring year-round production or optimal efficiency.

Medium temperature applications are those for most current domestic, commercial, or agricultural hot water requirements. The range here is from 90 to 180 degrees F. Most washing, cleaning, showering, and soaking needs fall into this range. The higher temperature uses are for some dishwashing and sterilization processes. Solar thermal systems can meet 40 to 80% of most conventional requirements.

Solar Space Heating Applications

The applications of solar space heating systems are much more restricted than those for hot water because far fewer retrofit opportunities exist. For existing structures, the thousands of dollars necessary to install a solar space heating system are generally better spent minimizing thermal requirements through insulation, weatherization, and even passive solar additions or structural changes. In the cases where a good southern exposure and adequate roof space exist, and the structure has minimal heating requirements, solar space heating may be viable. However, retrofit applications are limited by economic considerations.

For new structures of any kind -- residential, commercial, agricultural, or industrial -- solar thermal space heating may be installed. The best applications are those with year-round heating requirements, such as exist in very cold, relatively clear climates. Others are those where the space heating system can be used in the summer season for hot water applications -- in a seasonal restaurant, for example, or a summer laundry. Whatever the use of the building, the system will only be a sound investment if it is designed to be an integral part of the structure. Solar system costs are much lower if incorporated into overall expenses for design and construction.

REQUIRED ENVIRONMENTAL CONDITIONS

Many environmental conditions affect the feasibility of implementing solar heating and cooling systems. In this section, several of the most important are briefly discussed. The additional information required to perform simplified feasibility assessments for active solar systems may be found in either Reference (2) or Reference (3), each of which presents a different calculation methodology.

Environmental conditions required for implementation of solar systems may be broadly divided into the categories of site design, building design, and the availability of solar energy for collection. Selection of a building site and the location and configuration of solar equipment on the site can have important effects on system performance and overall feasibility. If solar power is being considered for a new building, virtually all architectural planning should be done with this in mind. Orientation on the building site, structural and interior space design, and the thermal efficiency of all building components should be carefully analyzed. Where a solar system is intended to replace or supplement the heating or hot water systems of an existing facility, the same factors are important, although there is less flexibility to change the building components to accomodate requirements for solar installation. Energy from the sun is available everywhere on earth.

but some locations are somewhat more favorable for solar energy collection than others. This is due to variables such as the average outdoor temperatures during the coldest times of the year, which affect both the demand for space heating and the efficiency of solar collectors.

Site Design

For retrofit projects, limited opportunities are available to use site characteristics to enhance the attractiveness of solar systems. However, a review of several important aspects of site design and configuration that bear on solar installations may help to identify potential applications. These aspects should also be considered during the early conceptual stages of design for new buildings. Site design can affect solar gain, natural ventilation of the building by local and prevailing winds, and other characteristics, such as potential safety hazards of solar systems.

Solar Gain

Solar collectors are ideally oriented true South, to maximize collection of the sun's rays during the winter when the sun is low in the sky. True South should be located with an isogonic chart or with the help of the local Weather Bureau, since a compass indicates magnetic South, which may differ by several degrees (15 or more in some cases). Orientation of the collectors as much as 15 degrees East or West of true South is generally permitted and not thought to affect performance. Solar gain can be increased if reflection from the ground and other surfaces is captured. Sand, snow light-colored gravel, and other highly reflective surfaces located adjacent to collectors can increase annual collected energy by as much as 4[illegible].

Solar gain may be seriously reduced by shading from chimneys, shade trees, adjacent buildings, or other parts of the collector array. This should be prevented, especially during the [illegible]

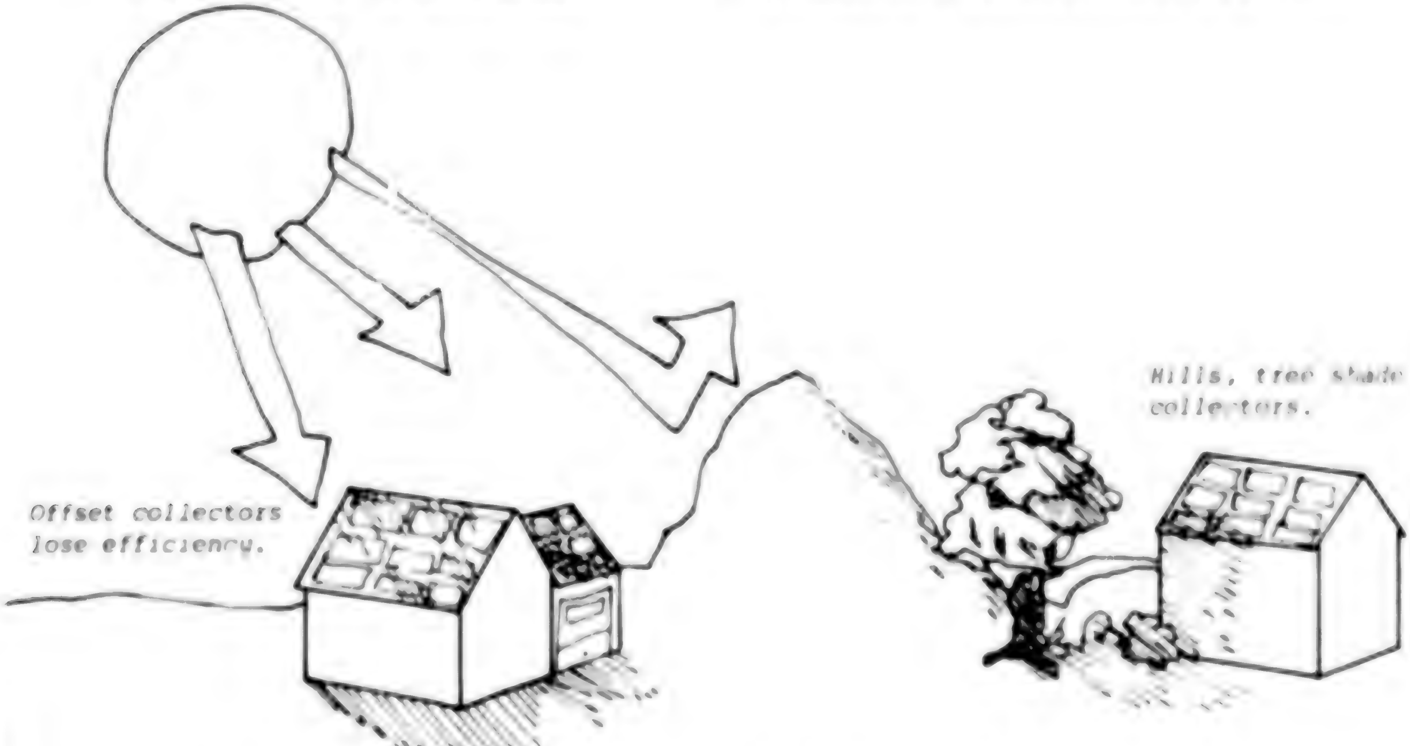

Offset collectors lose efficiency.
Hills, tree shade collectors.

Figure 4. Factors Affecting Efficiency of Solar Collectors

between 9 am and 3 pm -- the most important for solar collection. Figure 4 shows a building with a solar array blocked by hills and a shade tree, and another with two arrays of collectors that are slightly offset because of the building design. Both will lose efficiency during certain parts of the day. Furthermore, the offset collector array could freeze up during the winter.

The possibility of shading due to future development should be carefully considered. If future construction reduces the availability of sun to the collectors, the life-cycle cost effectiveness of the system will be reduced. Since collector arrays face South, placing them in the northern part of the site will reduce the likelihood that future off-site development could shade them. Deciduous trees standing on the south side of a solar-heated building can help to provide shade and natural ventilation in the summer when heating demands are low, and present almost no barrier to solar penetration in the winter, when their leaves have fallen.

Winds are the most variable factor to be considered in site design for solar implementation, since they are greatly shaped and directed by topography and landscape (see Wind section for more detail). Wind alters the efficiency of solar systems in several ways: high winds can affect the structural soundness of rack-mounted collectors, and cold winds can reduce collector efficiency, drawing off heat that would otherwise be stored. Wind blows hard at the crest of a hill and cold air collects in depressions, making midslope locations better for solar installations in hilly areas.

Buildings, fences, walls, parapets, and control devices may be useful as windbreaks. Evergreens planted to the north of a building or a free-standing collector array will cut arctic winds and protect against heat loss.

Evaluating a site for potential solar applications requires that many prime items be considered. Presence of subsurface water at a solar site can seriously affect the thermal performance of a storage tank or rock bin located below ground. The water will cause heat to diffuse more easily into the surrounding earth, drastically affecting system performance.

Safety considerations are an important aspect of solar installations that should not be overlooked. Reflected sunlight may be visually distracting to passers-by, and may cause a serious problem for drivers if the project faces a road. Collector surfaces may heat rapidly in the winter, causing accumulated snow to slide off. Broken heat transfer lines will drip hot fluid that can injure people and damage building materials. Systems should be installed where unwanted access can be prevented, so that vandals won't damage the collector surfaces. However, systems should be accessible for repair and maintenance.

Building Design

While numerous possibilities exist for application of solar thermal systems, by far the most common is in space heating and provision of domestic or basic service hot water. Accordingly, the environmental conditions affecting production will be much the same as those considered in the installation of conventional HVAC and hot water systems, with important exceptions. The thermal load of the building, its design heat loss, and the indoor and outdoor design temperatures are critical factors in reaching a judgment of the feasibility of solar system. The efficiency of collectors depends on both their design and environmental factors, and can be altered depending on how they are installed. At the site, the building and its collectors must take advantage of the "solar window" through which most of the solar energy useful for collection must pass.

Solar Window

By imagining the sky as a dome over the building or facility selected as a potential solar project, you can define the solar window for the project. At the top of the window is the line drawn by the sun's path on June 21, the day it's highest in the sky. At the bottom is the line drawn on December 21, the day when it reaches its lowest point in the sky. The edges of the window are drawn by the sun's position at 9 am and at 3 pm, the two outside limits for useful collection. (See Figure 5.) This window, which changes depending on the latitude of the project, must be clear of obstructions that would shade the collectors as discussed above.

Collector Tilt

Because the degree of latitude will affect the angle at which the sun's rays reach the site, collectors must be installed at different tilts for different locations. The optimum tilt for collectors is usually equal to the latitude plus 15 degrees for space heating, or the latitude plus 5 degrees for combined heating and cooling. This factor influences sizing of collectors, as will be discussed below under Production Potential. Deviation of up to 10 degrees from the optimum angle is acceptable, but will have an effect on system performance. Collectors may also be tilted to effectively capture the reflection from an adjacent ground or building surface, and to reduce the likelihood that snow will accumulate on the collector surface.

Collector Efficiency

As discussed above under Technology, the efficiency of collectors varies considerably with their design, construction, and the materials used. This becomes very important as the collector interacts with the environment. For example, where the temperature of the transfer medium entering the collector inlet is relatively close to that of the air surrounding the collector (ambient air), the collector performs at a relatively high efficiency because the surrounding air doesn't hinder the heating process. But as the difference between the collector inlet temperature and the ambient air temperature increases, efficiency drops. Where these temperature differentials exist, such as in

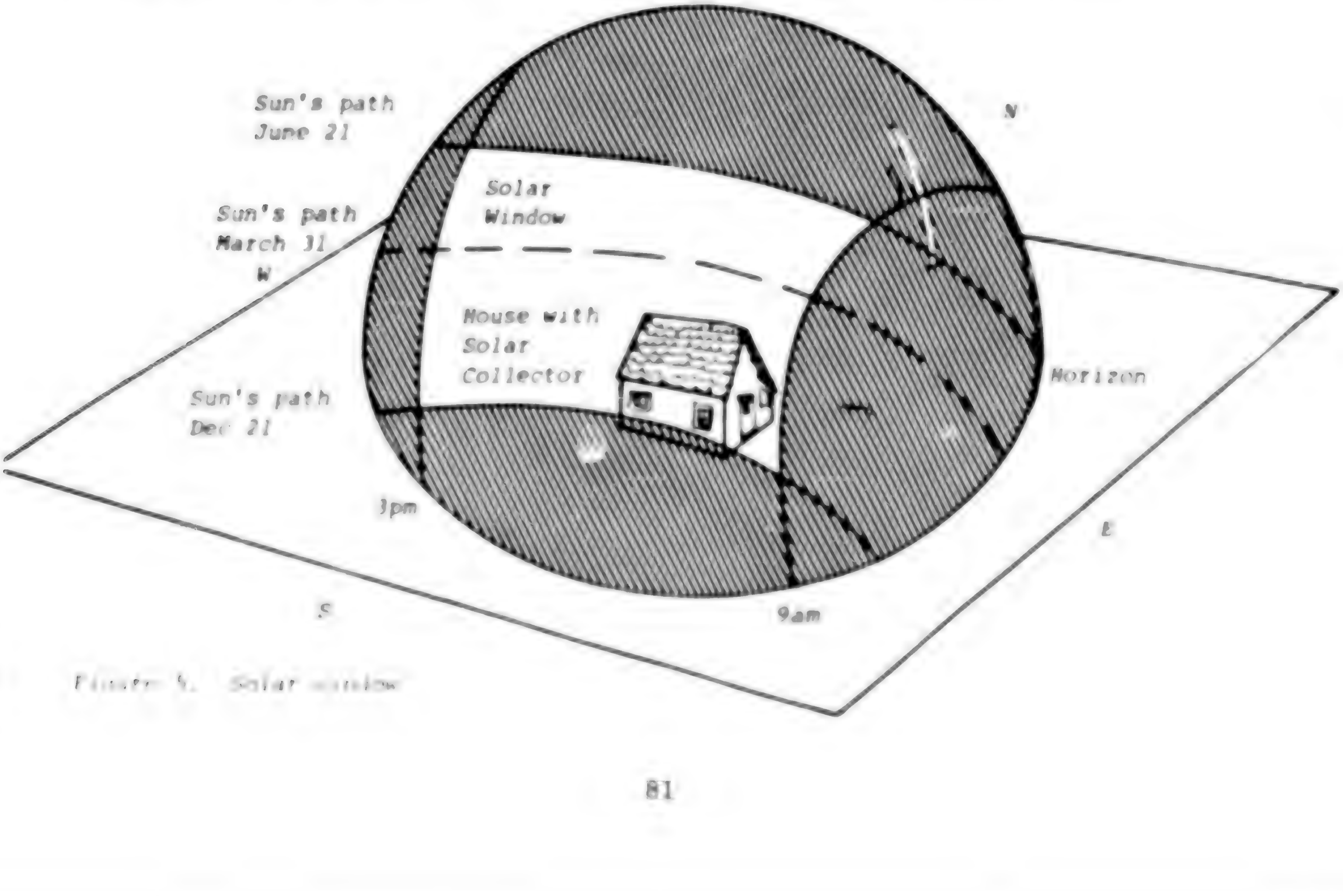


Figure 5. Solar window

colder climates, collectors with high design efficiencies and special materials may be called for, or the system may have to be sized differently to allow for less efficient performance.

Building Thermal Load

While the thermal load of buildings has virtually no influence on the demand for domestic or basic service hot water, it has a pronounced influence on demand for space heating. Solar systems providing hot water only may therefore be sized on the basis of annual averages, since demand is fairly constant. Rough estimates of demand for space heating may be based on annual data, but accuracy can be increased by using monthly loading data.

We require space heating systems for buildings because they lose heat through all of the building sections -- walls, windows and doors, floors and ceilings -- and because they are subject to losses due to infiltration and the air changes needed for adequate ventilation. Heat losses through the wall sections vary considerably depending on the differences between indoor and outdoor temperatures and on the thermal resistance of a specific building component. As the difference between indoor and outdoor temperatures increases, the transmission of heat through the structure increases. Many methods are available for calculating the thermal load of buildings, because it is a standard requirement for analysis of HVAC requirements.

3. Solar Energy Available for Collection

The availability of solar energy for collection is influenced by many factors. The sun's angle with respect to the collector surface, the latitude of the project, and shifts in local atmospheric conditions all affect collection potential at a given location.

As discussed above, collectors must be positioned to take maximum advantage of incoming direct solar radiation. Proper collector tilt can only be determined when the position of the sun is known for different times of the day and year. This varies throughout the year and depends upon the latitude of the project -- the further from the equator and/or the higher the latitude, the greater the collector tilt required.

Collectors can use both direct and diffuse solar energy. Direct radiation comes directly from the sun, without change of direction, while diffuse radiation is that available after its direction has been changed by atmospheric conditions. The amount of solar radiation -- or *insolation* -- reaching collectors can be reduced by normal climatic conditions such as cloudiness, rain, and snow. Concentrations of water vapor, dust, and smoke will also cut energy available to be captured. When sunlight must travel a longer distance through the earth's atmosphere to reach the surface, as it does in the morning and evening, its intensity at the site of the collectors will be reduced. Because the sun drops lower in the sky during winter months, a similar variation occurs on an annual basis.

When these factors are quantified, estimates of insolation can be made for different locations on a monthly and annual basis. The importance of such calculations is shown in Table 2, prepared from climate and solar data for typical weather years in a number of U.S. cities. As you can see, Seattle, Washington, receives only 53% of the insolation received in Albuquerque, New Mexico. Accordingly, to meet the same energy demand, a solar system in Seattle would have to be twice as large or twice as efficient as one in Albuquerque. The resulting impact on cost and feasibility is obvious.

Procedures for calculating available insolation are now widely available. Chapter 59 of the *ASHRAE Applications*

Table 2. Annual Insolation on Tilted Surface (LAT + 10^{o})
(Source: Reference (2))

Closest City and Weather Year	*10^3 Btu/SF_C*
Madison, WI (61)	599
Dodge City, KS (55)	776
New York, NY (58)	524
Bismarck, ND (54)	602
Richland, WA (53-70)	613
Pocatello, ID	668
Lincoln, NB (58)	679
Los Alamos, NM (74)	663
Davis, CA	680
Nashville, TN (55)	564
Page, AZ	699
Miami, FL (59)	672
Albuquerque, NM (62)	798
Charleston, SC (53)	598
Boston, MA (57)	554
El Paso, TX (54)	812
Forth Worth, TX ([illegible])	652
Fresno, CA (57)	623
Lake Charles, LA (57)	580
Los Angeles, CA (63)	665
Medford, OR (61)	571
Phoenix, AZ (62)	764
Santa Maria, CA (56)	751
Seattle, WA (63)	422
Tallahassee, FL (59)	617

Note: Year chosen is most representative of typical conditions for which complete data are available. For individual sites not listed, either interpolate from the data above or use actual site data.

Handbook (4) contains clear-day data that can be used for this purpose, and the *Department of Energy Facilities Solar Design Handbook (2)* contains several other helpful estimation methods.

PRODUCTION POTENTIAL

Examining the potential production of solar systems can be an extremely sophisticated procedure involving use of computer simulation techniques that allow evaluation of the many different elements of the system, and the dynamics of their interaction over time. These procedures are discussed in Reference (2), a handbook for engineering assessments. A somewhat simplified procedure using the "f" chart method developed at the University of Wisconsin is presented in Reference (3). This technique will be quite valuable to those who wish to check solar feasibility assessments and design studies prepared by architectural and engineering firms or other contractors. Three simpler and much less precise methods for sizing solar equipment are discussed below. The first of these is a set of simple rules of thumb now used in the trade. The second is a technique for sizing hot water systems using insolation data and approximations of system efficiencies. The third is a simplified sizing technique adapted from the Installation Standards developed by the Sheet Metal and Air Conditioning Contractors National Association (SMACNA) with HUD support (Reference (4)).

Rules of Thumb

Quick assessments can be made using rules of thumb, but we stress that variations in building design, installation, climate, and demand for energy can cause errors of 100% or more. Use rules of thumb as general guidance only.

Solar hot water systems are often sized to bear an estimated 75% of total requirements. The rule of thumb calls for one square foot of collector for each gallon of hot water required per day. As an example, if a family of four uses an average of 20 gallons per person, per day (a total of 80 gallons per day), then 80 ft^2 of collector will furnish 75% of total hot water requirements in a sunny climate. A larger collector area would be needed to meet 100% of requirements, or to deliver 75% if the family lived in a cold, cloudy, windy climate.

Considerable experience with residential applications of solar space heating systems has been obtained through the HUD solar demonstration program. The rule of thumb used by the industry was that to supply two-thirds to three-fourths of heating needs, collector area should be 25 to 50% of heated floor area, or one ft^2 of collector for every 2 to 4 ft^2 of heated floor. This would mean that 2/3 to 3/4 of heating needs for a well-built house of 1,500 ft^2 in a cold, sunny climate could be supplied with 500 ft^2 of collector. However, HUD experience shows that, depending upon the project, one ft^2 of collector heated as many as 9 and as few as 2.3 ft^2 of floor area. *The average was 8.87 ft^2 of floor area per ft^2 of collector.* These variations result in part from different estimates of energy demand and system efficiency. The more efficient and well-insulated the collector, pipes, and storage, the smaller will be the required collector area.

Rules of thumb for storage displayed a similar variation. Rock bins used as storage with air systems will take up about .5 cubic feet for each ft^2 of collector. Storage tank capacity for water systems is estimated at 1 to 2 gallons for each ft^2 of collector. In the HUD program, *liquid storage capacity* ranged from .9 to 6.2 gallons per ft^2, with *an average of 2 gallons per ft^2*. Rock bins ran .4 - 1.9 cubic feet per ft^2 of collector, with *an average of .8 cubic feet per ft^2*.

Hot Water Sizing

A simplified method for sizing solar hot water systems uses annual figures for available solar insolation, and an estimated efficiency for the solar system.

SOLAR THERMAL

Estimated conversion efficiencies may be obtained by talking to technical professionals familar with solar systems or with manufacturers' representatives and system suppliers. Data for annual solar insolation in several U.S. locations are presented in Table 2 (above). Figures for hot water heating requirements should be obtained from your own plans and records. If you have worked through the Buildings or Water Conservation sections of the Planbook, you may also have prepared calculations of energy use and potential savings in this area.

To figure the amount of collector area needed, multiply available insolation per ft^2 of collector for your location by the percentage of efficiency of the conversion system. This gives a figure (Y) in MBtu/ft^2 for energy available to heat water. Then, multiply the total heating load by the percentage of the load you want to supply with the solar system. This gives a figure (X) in MBtu for the amount of solar energy you'll require from the system. Square footage required is given by the formula X/Y.

Example: A house in Gatlinburg, Tennessee, uses 19.48 MBtu annually to heat hot water. Looking at Table 2, we find an insolation figure of 564 x 10^3 Btu/ft^2 (or .564 x 10^6 Btu/ft^2) for Nashville, Tennessee, the closest city to Gatlinburg. We want the system to provide 72% of total hot water requirements. On the basis of conversations with specialists, we believe the solar hot water system will be 50% efficient. Accordingly, we calculate as follows: If

$$.564 \times 10^6 \text{ Btu/ft}^2 \times .50$$

$$= .282 \times 10^6 \text{ Btu/ft}^2$$

$$= Y,$$

and

$$19.48 \times 10^6 \text{ Btu} \times .72$$

$$= 14 \times 10^6 \text{ Btu}$$

$$= X,$$

then,

$$X/Y = \frac{14 \times 10^6 \text{ Btu}}{.282 \times 10^6 \text{ Btu/ft}^2}$$

$$= 49.6 \text{ ft}^2$$

Based on this rough estimate, a 50 ft^2 collector array should supply approximately 72% of the hot water requirements of the house.

SMACNA Technique

SMACNA has prepared a set of tables (presented below as Table 7) that can be used to size an air or liquid solar system. The tables were prepared using a solar system with typical efficiencies, and climate and insolation data for different parts of the country, to give conversion factors that can be used with a simple formula:

$$\text{Collector Area (ft}^2) = \frac{\text{Design Heat Loss}}{\text{Conversion Factor From Table 7}}$$

As you will see, using the technique will be simple, once you have obtained a figure for Design Heat Loss.

Design Heat Loss is a term that means the total thermal transmittance of a building in Btu/hr. It is different than figures for actual fuel consumption obtained from utility bills and other records. However, for most existing and newly designed buildings, this figure should have been calculated when heating, ventilation, and air conditioning systems for the structure were sized and installed. If you cannot find the information in your records, there is an excellent discussion of the subject in Reference (1) entitled "Building Heat Losses." So that you'll be able to use the SMACNA tables, a brief description of the process is given here, with useful examples and several helpful tables. We'll use as an example a house in Oxon Hill, Maryland.

Table 7. Solar Conversion Factors for United States, Australia, and Canada (Adapted from reference 4)

Location	Design Temp. Difference	AIR						LIQUID					
		Portion of Load Carried By Solar											
		30%		50%		70%		30%		50%		70%	
		Collector Tilt											
		37°	53°	37°	53°	37°	53°	37°	53°	37°	53°	37°	53°
UNITED STATES													
Alaska													
Annette	75	169	178	68	82	28	37	163	174	60	73	25	32
Fairbanks	120°	*147	136	*69	56	*32	24	*147	132	*63	48	*28	21
Arizona													
Page	38°	202	205	105	110	60	65	221	227	110	116	63	68
Phoenix	45°	533	556	276	293	163	177	591	615	294	314	172	187
Tucson	38°	461	477	236	248	147	155	511	526	252	267	149	160
Arkansas													
Little Rock	55°	222	232	106	112	62	68	235	245	108	115	58	63
California													
Davis	40°	231	240	108	113	54	60	246	257	106	117	50	58
Inyokern	25	316	331	160	173	96	107	350	369	172	187	100	111
Fremont	32°	285	277	133	134	72	77	307	299	137	139	70	74
Fresno	45	289	296	134	144	66	73	311	320	135	146	66	74
Livermore	40°	315	315	150	157	84	91	338	342	158	164	82	91
Los Angeles	30°	440	421	214	218	127	130	484	465	234	226	131	130
Napa	36°	226	221	102	105	53	55	235	234	101	105	47	53
Pittsburg	35	203	207	89	95	45	50	216	221	88	96	40	46
Redwood City	35	286	283	133	138	71	77	303	304	137	142	68	74
Richmond	32°	238	228	110	111	58	62	249	240	110	111	55	59
Riverside	40°	533	531	260	270	156	163	581	581	284	292	164	172
San Francisco	33	279	258	128	127	66	70	290	270	130	127	63	66
San Jose	34°	284	280	131	135	71	76	301	298	134	138	66	73
Santa Maria	36°	471	438	227	241	140	143	514	478	263	249	146	142
Colorado													
Denver	70°	304	315	159	171	94	104	246	257	106	117	50	58
Grand Jct	70°	281	298	146	157	83	90	305	322	148	161	80	91
Grand Lake	75	232	224	119	120	68	71	246	240	122	123	66	70
Boulder	62°	242	251	123	129	72	78	259	267	125	122	68	75
District of Columbia													
Washington	57°	140	149	74	80	40	44	159	169	73	79	37	41
Florida													
Apalachicola	38°	459	473	242	250	148	153	507	522	254	265	150	157
Gainsville	38°	447	458	240	247	148	153	492	504	251	259	148	154
Miami	22°	1257	1265	670	685	415	430	1385	1396	719	741	427	443
Tallahassee	45°	488	507	278	288	165	175	538	557	269	280	156	163
Tampa	31°	689	705	395	405	228	235	760	777	403	428	241	246

*Use 75° tilt angle in lieu of 37° tilt angle

Table 7, (Continued)

Location	Design Temp. Difference	AIR						LIQUID					
		Portion of Load Carried By Solar											
		30%		50%		70%		30%		50%		70%	
		Collector Tilt											
		37	53	37	53	37	53	37	53	37	53	37	53
Georgia													
Atlanta	55	292	297	141	150	80	96	310	316	144	152	78	84
Griffin	48	321	337	162	170	98	105	350	367	166	177	93	101
Idaho													
Boise	60	196	205	89	99	45	52	205	217	88	99	40	48
Pocatello	72	235	245	113	123	60	68	252	266	114	125	56	66
Twin Falls	62	186	189	86	91	44	50	193	197	84	90	40	46
Illinois													
Chicago	70	74	78	29	32	14	16	67	70	25	28	15	15
Lemont	70	162	167	77	83	42	47	167	176	74	82	38	43
Indiana													
Indianapolis	64	147	154	67	71	32	40	151	156	64	70	30	35
Iowa													
Ames	77	182	195	88	97	49	56	189	204	86	96	44	52
Kansas													
Dodge City	63	291	304	149	158	87	96	317	330	156	168	86	96
Manhattan	66	197	208	96	104	54	61	208	219	96	105	50	57
Kentucky													
Lexington	60	212	222	99	106	55	60	221	232	99	107	50	56
Louisiana													
Lake Charles	37	324	332	170	176	106	110	353	361	175	181	100	104
New Orleans	35	261	267	136	139	82	84	279	282	135	139	74	77
Shreveport	44	246	254	124	129	77	80	263	270	126	132	70	75
Maine													
Caribou	84	158	168	74	83	39	47	163	175	71	81	34	41
Portland	70	183	191	88	97	50	55	192	203	88	96	45	52
Maryland													
Silver Hill	54	183	191	90	97	50	55	195	206	91	99	47	53
Massachusetts													
Amherst	75	134	144	64	71	31	37	134	139	55	61	25	29
Blue Hill	70	159	165	87	94	46	51	163	172	73	80	37	42
Boston	70	148	157	72	80	35	42	150	159	66	73	33	38
Lynn	60	119	126	56	60	29	31	119	125	51	56	23	27
Natick	70	159	165	88	94	48	52	165	172	73	80	37	42
Michigan													
East Lansing	70	113	119	49	54	26	29	115	121	47	52	22	26
Sault Ste. Marie	78	159	166	73	79	36	43	162	172	68	77	31	38
Minnesota													
St. Cloud	95	175	187	96	108	52	63	212	231	95	109	48	58

Table 7. (Continued)

Location	Design Temp Difference	AIR						LIQUID					
		Portion of Load Carried By Solar											
		30%		50%		70%		30%		50%		70%	
		Collector Tilt											
		37	53	37	53	37	53	37	53	37	53	37	53
Missouri													
Columbia	70	219	230	105	114	54	60	230	243	104	113	53	61
Montana													
Glasgow	90	231	254	108	124	58	71	244	272	108	127	54	68
Great Falls	86	244	265	118	129	62	74	258	278	115	131	57	70
Summit	75	141	144	64	70	29	35	143	148	59	65	[illegible]	30
Nebraska													
Lincoln	70	210	225	101	110	57	65	221	235	102	113	53	61
N Omaha	71	204	215	101	110	56	63	217	235	101	113	54	62
Nevada													
Ely	72	304	304	154	159	91	98	331	332	162	168	91	98
Las Vegas	50	410	433	199	216	123	135	452	479	217	237	127	141
New Jersey													
Seabrook	55	153	160	74	74	40	45	158	166	72	78	36	41
New Mexico													
Albuquerque	60	373	387	144	209	116	124	412	429	207	220	117	128
New York													
Albany	70	153	160	73	80	37	59	155	165	69	77	32	38
Ithaca	70	114	120	51	56	27	30	114	120	46	51	22	25
N Y C	55	131	138	62	67	34	39	133	141	60	66	30	34
Upton	55	165	172	79	84	44	49	172	180	78	85	40	45
Sayville	50	150	155	72	76	40	45	155	162	71	78	37	41
Schenectady	71	112	119	46	51	18	21	111	119	48	53	24	28
North Carolina													
Cape Hatteras	48	338	346	168	179	98	106	370	379	178	188	99	107
Greensboro	60	245	253	118	126	66	73	259	269	123	130	65	71
Raleigh	55	273	283	134	141	80	87	292	295	143	152	79	86
North Dakota													
Bismark	89	208	226	98	111	53	63	196	217	87	102	44	54
Ohio													
Cleveland	63	123	127	55	58	27	29	124	128	50	54	23	26
Columbus	63	131	141	62	67	32	35	138	144	58	63	27	31
Put In Bay	63	129	134	56	60	28	32	129	134	52	57	24	28
Oklahoma													
Stillwater	57	243	252	118	126	70	75	257	269	121	129	66	72
Oklahoma City	60	306	319	149	159	90	96	330	345	160	171	89	98
Oregon													
Astoria	47	141	139	59	64	26	31	142	140	55	59	22	26
Corvallis	47	129	131	54	59	23	27	130	133	48	53	20	22
Medford	55	168	171	74	80	46	54	171	176	68	75	27	31

Table 7. (Continued)

Location	Design Temp. Differ- ence	AIR						LIQUID					
		Portion of Load Carried By Solar											
		30%		50%		70%		30%		50%		70%	
		Collector Tilt											
		37°	53°	37°	53°	37°	53°	37°	53°	37°	53°	37°	53°
Pennsylvania													
Pittsburgh	65°	63	66	25	27	16	18	62	64	25	26	15	15
State College	64°	130	140	60	66	30	35	131	137	55	61	26	30
Rhode Island													
Newport	59°	165	169	82	87	46	50	173	179	80	85	41	45
South Carolina													
Charleston	47°	299	313	151	160	95	101	327	344	160	171	94	100
South Dakota													
Rapid City	76°	250	264	125	137	71	81	270	289	128	141	68	79
Tennessee													
Nashville	60°	211	215	96	103	54	60	215	223	93	100	47	52
Oak Ridge	58°	179	183	81	85	46	50	184	189	80	86	40	44
Texas													
Big Spring	48°	369	341	169	176	95	106	359	373	171	181	98	105
Brownsville	30°	559	559	310	311	193	198	625	608	317	319	185	188
El Paso	45°	404	415	205	209	122	132	446	461	218	231	138	137
Ft. Worth	50°	341	350	186	194	114	118	369	382	179	189	102	110
Midland	55°	402	416	204	211	121	126	442	454	213	225	123	131
San Antonio	40°	378	387	196	204	121	128	415	421	205	212	119	124
Utah													
Salt Lake City	70°	230	237	109	120	57	63	244	254	111	120	54	63
Virginia													
Mt. Weather	60°	170	177	85	90	49	51	180	186	84	90	44	49
Washington													
Prosser	55°	183	195	78	90	35	43	191	205	75	88	30	39
Pullman	65°	196	217	84	100	42	52	201	223	81	97	36	46
Richland	55°	132	143	55	65	23	29	135	146	56	61	20	25
Seattle	55°	162	168	56	62	22	27	158	166	52	61	22	28
Spokane	70°	155	170	74	85	50	60	171	193	70	82	30	39
Wisconsin													
Madison	80°	135	142	66	72	32	38	172	184	75	83	37	43
Wyoming													
Lander	82°	313	323	160	171	92	105	341	360	166	181	93	106
Laramie	73°	259	267	133	138	79	86	279	287	136	144	76	84

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Table 7, (Continued)

Location	Design Temp. Difference	AIR						LIQUID					
		Portion of Load Carried By Solar											
		30%		50%		70%		30%		50%		70%	
		Collector Tilt											
		37°	53°	37°	53°	37°	53°	37°	53°	37°	53°	37°	53°
CANADA													
Alberta													
Edmonton	96	*204	201	*99	95	*54	51	*211	209	*97	93	*48	45
Lethbride	94	238	255	107	123	55	68	243	268	105	124	50	63
British Columbia													
Vancouver	51°	97	102	34	40	16	18	87	94	29	34	15	17
Manitoba													
Churchill	108°	*152	151	*77	75	*43	40	*157	155	*75	72	*38	35
Winnipeg	100°	*150	146	*80	77	*45	42	*206	204	*97	95	*51	49
New Brunswick													
Moncton	77°	122	127	53	59	25	30	120	126	47	54	21	26
Newfoundland													
St. Johns	64°	90	89	39	41	17	21	85	87	33	37	17	18
Ontario													
Ottawa	83°	152	162	71	78	36	44	156	168	67	76	32	39
Kapuskasg	98°	119	127	53	62	25	32	115	128	48	57	22	28
Toronto	70°	121	127	55	59	28	32	120	127	49	55	24	28
Quebec													
Montreal	80°	112	119	49	56	22	27	110	119	43	50	20	24
AUSTRALIA													
Adelaide	30°	172	181	88	94	54	59	186	197	90	97	51	55
Melbourne	32°	111	120	56	61	35	38	118	128	55	61	30	34
Perth	28°	295	306	151	158	95	100	323	338	158	166	91	97
Sydney	28°	314	332	162	171	102	109	345	367	169	180	98	106

***Use 60° tilt angle in lieu of 37°.**

Design Heat Loss is computed with the formula $A \times (t_i - t_o) \div R_t$ where A = the surface area of the building in ft^2, $t_i - t_o$ = the difference between indoor and outdoor temperatures in degrees F, and R_t = the total thermal resistance or R-value of all sections of the building. To figure R_t, you must add the R values of each component of a building section to arrive at the value for the whole section. The R values of building components are given in the ASHRAE Handbook. Several common ones are presented in Table 3. The higher the R factor, the less heat is transmitted per hour. In performing these analyses, expecially for glass areas, the inverse of R is sometimes used, called the U value: U=1/R. If you use U value in place of R value, the formula for Design Heat Loss becomes $DHL = A \times (t_i - t_o) \times U$, which yields the same result as the formula stated above.

To arrive at an accurate measure of a building's heat loss, an estimate of infiltration heat losses is also needed. To figure infiltration, use the formula

$$H_i = C \times L \times Q \times (t_i - t_o),$$

where H_i is the heat loss due to infiltration; C is the heat capacity of air (.018 Btu/ft^3/degree F); L is total crack length in feet; and Q is the rate of air leakage in cubic feet per hour, per crack. Useful data on air infiltration are given in Table V, on p. 18 of Reference (2).

Finally, to make these figures apply on an annual basis, you replace the figure for $(t_i - t_o)$ with a figure based on annual degree days (ADD) which can be easily found in standard ASHRAE references, the Survey Manual (5), or from your local utility or weather station. To make the change, divide by $(t_i - t_o)$ and multiply by ADD and 24, for the number of hours in a day.

Examples

Our sample home is located in Oxon Hill, Maryland, a suburb of Washington, D. C., approximately 5 miles from Andrews Air Force Base. It is a 4 bedroom, 2 story colonial with full walk-out basement, with half of the basement wall area exposed, and half facing the soil. The house has an attached 2-car garage on the west end. All windows, with the exception of one small one, are on the north and south sides of the house. There are storm doors leading from the walk-out basement and from the family room on the first floor. Both storm doors are on the north side of the building. The first floor front of the house has a brick face over frame construction. The house is a total electric home, and Maryland law requires that all total electric homes be insulated in all outside walls and in the floor between the first floor and basement, as well as 6 inches of insulation in the attic for the ceiling.

First, we'll calculate R values for one wall in the residence we're using as an example. The wall is brick-faced over frame construction. R_t for this section is computed as follows:

Component	R-value
Wall:	
Outside Air (15 mph)	.17
4" brick facing (.11 x 4)	.44
3/8" plywood	.47
3 1/2" glass wool insulation	11.00
1/2" drywall	.45
Inside Air (still)	.68
Total (R)	13.21
U-value ($1/R_t$)	.07

The following table shows calculations for the envelope heat loss of the home. The first column gives the difference between indoor and outdoor temperatures at each section, the second shows area in ft^2, and the third gives the R value of the section. Using the formula

$$\frac{A \times (t_i - t_o)}{R_t}$$

Table 3. R-Values for Common Building Materials
(from the ASHRAE Handbook of Fundamentals - 1972)
(Source: Reference (4)).

Material	*R-Values*	
	per inch	*total*
WALL & CEILING		
Hardwood	.91	--
Softwood	1.25	--
Aluminum Siding	--	.61
Plywood (1/2")	--	.62
Gypsumboard (1/2")	--	.45
Insulating board sheathing (1/2")	--	1.32
Slab Door	--	2.37
FLOOR		
Wood subfloor (25/32")	--	.98
Cork tile (1/8")	--	.28
Tile (asphalt, linoleum, etc.)	--	.05
Carpet with rubber pad	--	1.23
Carpet with fibrous pad	--	2.08
Building paper	--	.06
COVERING		
Plaster	.20	--
Acoustic tile (3/4")	--	1.78
Asphalt roll roofing	--	.15
Asphalt shingles	--	.44
GLASS		
Flat Glass (1/8")	--	.88*
Insulating glass, double (1/4" air gap)	--	1.54*
Storm windows, double (1/4" air gap)	--	1.79*
Plastic bubble (skylight)	--	.67*
Storm door (4" air gap)	--	3.55*
BRICKS-CONCRETE		
Brick, facing	.11	--
Concrete or stone	.08	--
Concrete block (solid, oven-dried)	.11	--
Concrete block (8" thick, 2 cores)	--	1.04
INSULATION		
Glass wool batt (3-3 1/2")	--	11.0
Glass wool batt (5 1/4" - 6 1/2")	--	19.0
Fiberglass board	4.35	--
Expanded polyurethane	6.25	--
Expanded polystyrene, white	4.05	--
Expanded polystyrene, molded beads	3.75	--
Loose fill insulation:		
Mineral wool	3.80	--
Cellulose fiber	4.05	--
AIR		
Inside (still)	--	.68
Outside (7 1/2mph)	--	.25
(15 mph)	--	.17

---

* *Includes effects of inside and outside air films.*

Table 4. Heat Loss Calculations for Sample Building

Components	$(t_i - t_o)$	Area (ft^2)	R	HL_T (Btu/hr)
Wall				
- Outside air film (15 mph)			0.17	
- 4" Brick, facing (4 x .11)			0.44	
- 3½" Glass wool insulation			11.00	
- ½" Gypsumboard			0.45	
- Inside air film (still)			0.68	
Total	49	257	R_t =13.21	953
Wall				
- Outside air film (15 mph)			0.17	
- Aluminum siding			0.61	
- Building paper			0.06	
- ½" plywood			0.62	
- 3½" insulation			11.00	
- ½" Gypsumboard			0.45	
- Inside air film (still)			0.68	
Total	49	1795	R_t =13.59	6,472
Wall (Basement exposed to air)				
- Outside air film (15 mph)			0.17	
- 8" concrete (8 x 0.08)			0.64	
- 1" air space			1.01	
- ½" Gypsumboard			0.45	
- Inside air film (still)			0.68	
Total	49	524	R_t = 2.95	8,704
Wall (Basement facing soil)				
- 8" concrete			0.64	
- Inside air film (still)			0.68	
Total	30	544	R_t = 1.32	12,364
Windows and Doors				
- Storm window w/4" air space	49	140	1.79	3,832
- Single pane	49	7.5	0.88	417
- Sliding doors (double pane, ¼" gap)	49	84	1.54	2,673
- Storm door (4" air space)	49	21	3.53	292
- Door to garage	49	21	2.37	434
Total				7,648
Floor (Basement)				
- 6" Concrete (6 x 0.08) w/carpet	10	600	2.68	2,239
- 6" Concrete w/o carpet	10	600	1.40	4,286
Total				6,525
Ceiling				
- Outside air film (15 mph)			0.17	
- Asphalt shingles			0.44	
- Asphalt roofing (roll)			0.15	
- ½" plywood			0.62	
- Attic air gap			0.85	
- 6" fiberglass batt			19.00	
- ½" Gypsumboard			0.45	
- Inside air film (still)			0.68	
Total	49	1200	R_t =22.36	2,630

Total Transmission Heat Loss = 45,296 Bt

Seasonal or

$$\text{Annual Transmission Heat Loss } (HL_{TA}) = \frac{HL_t \times 24 \times ADD}{t_i - t_o} = \frac{45{,}296 \times 24 \times 4224}{49} = \underline{\underline{93.71}}\ \text{MBtu}$$

Where: 24 is number of hours per day and ADD (4,224) is the annual heating degree days for Washington, D. C.

to calculate heat loss, the figures in the first column are multiplied by those in the second and the product is divided by the figure in the third column to give a heat loss figure for the section in Btu/hr.

Once the figure for heat loss due to transmission has been obtained, heat loss due to infiltration must be calculated. As explained above, the formula for this is

$$H_i = C \times L \times Q \times (t_i - t_o)$$

and the formula for seasonal or annual heat loss is

$$SH_i = C \times L \times Q \times 24 \times ADD$$

For the sample house, infiltration losses are as follows:

Table 5. Infiltration Heat Losses (All doors and windows weatherstripped)

			Infiltration Heat Losses	
Cracks around:	*Length (ft)*	*Q-Value ($ft^3/hr/ft$)*	*Design Btu/hr.*	*Seasonal (Million Btu)*
Windows (storm/wood sashes)	*140*	*24*	*2,964*	*6.13*
Window (Res. Casement)	*7.5*	*52*	*344*	*0.17*
Patio Doors (Double hung/metal sash)	*52*	*32*	*1,468*	*3.04*
Doors, storm (2)	*42*	*34*	*1,259*	*2.61*
		Total Infiltration Heat Losses	*6,035*	*12.49*

Adding the figures for transmission and infiltration, we arrive at total figures for the design and seasonal heat losses of the sample house:

	Design (Btu/hr.)	Seasonal (million Btu)
Total Transmission	45,296	93.71
Total Infiltration	6,035	12.49
	51,331	106.20

Once a figure for total heat loss has been determined, computation of the required collector area using the SMACNA tables is relatively simple. The following problem illustrates the method used.

Problem: Using the sample house, with a Design Heat Loss of 51,331 Btu/hr., calculate the size collector required to yield a 70% annual fuel savings, if the collector tilt is 53 degrees.

Solution: In Table 7, we locate Silver Hill, Maryland, the closest point to Oxon Hill. Under the liquid column, we find for a collector tilt of 53 degrees and a fuel savings of 70%, the conversion factor of 53. Using the formula

$$\text{Collector Area} = \frac{\text{Design Heat Loss}}{\text{Conversion Factor}}$$

we have CA = $51{,}331/53 = 969\ \text{ft}^2$, which can be rounded upwards to $980\ \text{ft}^2$. For a 50% reduction in the use of conventional fuels, the collector size would be

$$CA = 51{,}331/99 = 518\ \text{ft}^2.$$

ECONOMICS

Is solar a good investment for your park, refuge, or hatchery? The question is simple; the answer is complex. To know why, you might compare buying solar to buying a house, rather than renting one.

When you buy a house, you slowly but surely gain ownership. When you have made the last mortgage payment, the house is yours, and there are no more payments. If you sell before paying off the mortgage, it is a safe bet that you will not lose money. In today's home market, you are likely to make a substantial return on your investment. To make a return, however, you must take care of your investment by maintaining and repairing the house. If you rent, you don't have to worry as much about maintenance and repair, but when it comes time to move, your rental dollars are lost forever.

Buying solar is somewhat the same, with a few important differences. When you buy a solar system, you are concerned with initial and lifetime costs. There are builders today who claim that their costs for building with hybrid or passive solar systems is close to the cost of building with conventional heating, ventilation, and air conditioning systems. If these new systems function properly, you can expect a short payback period. Using solar energy will pay for the extra cost of the system in relatively few years.

If however, you are looking at installing an active system, your initial costs will be higher than for a conventional system and the simple payback period (SPP) will be longer. You will, in a sense, be buying several years' supply of energy at one time. With both active and passive systems you must be concerned about durability. Maintenance and repair costs, if higher than those for a conventional system, will add time to the SPP. However, when the system has paid for itself out of savings, you will have a free energy source. This is like the end of the mortgage, when you finally own the home. If you rely on conventional fuels, it would be like renting: there is no hope of ever regaining the dollars spent on fuel.

Nonetheless, if the initial costs are prohibitive and the payback period too long, then it is not smart to install solar at your park, refuge, or hatchery. Conventional systems are for you. If SPP is 10 years and the system life is expected to be 20 to 25 years -- a normal lifetime for most well-engineered, durable systems -- then it could be considered a worthwhile investment, to be ranked against other conservation opportunities.

To estimate solar system costs, you can use the dollar values for different components and total installed systems that are presented in Table 6 below (modified from Table 4-7 in Reference (2)).

In using the figures for system costs by type, note that for smaller systems you should estimate by using a figure at the high end of the range. For instance, a 25 ft^2 collector system installed may cost \$52-55 per ft^2, while a 1000 ft^2 system may cost \$24 per ft^2. More accurate information on system costs may be obtained by checking with manufacturers or local contractors, once you have a general estimate of the square

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Table 6. Solar System Cost Estimates For Buildings

A.	*Subsystem Costs*	*Fraction of Total Solar Cost*
1.	*Collectors and supports*	35%
2.	*Storage and heat exchangers*	20%
3.	*Piping, controls, electrical, and installation*	45%

B.	*Component Costs*	*Costs/ft_c^2*
1.	*Collectors*	$5.00-20.00
	a. Nonselective	$5.00-10.00
	b. Selective	$10.00-20.00
	c. Collector support structure	$3.00-10.00
2.	*Heat exchangers*	$0.40-0.80
3.	*Collector fluid*	$0.15-0.20
4.	*Storage tank and insulation*	$2.00-5.00
5.	*Piping, insulation, expansion tanks, valves*	$3.00-6.00
6.	*Pumps*	$0.50-1.00
7.	*Controls and electrical = $300-5000*	

C.	*Systems Costs by Type*	*Installed Cost/ft_c^2*
1.	*HW only (10-99 ft^2)*	$35-55
2.	*HW only (100 ft^2 and above)*	$20-35
3.	*Space heating only*	$20-40
4.	*Space and BSHW heating*	$25-50
5.	*Space heating and cooling*	$35-65

Notes:

1. *These costs do not include auxiliary energy equipment, engineering design and inspection, or contingency costs.*

2. *Costs for retrofit projects are approximately 10 to 25% higher than the above.*

3. *B. 7. change to = $300-5000 to include simple controls for small buildings or residences.*

4. *ft_c^2 = collector area.*

footage you need.

To estimate SPP for installation of **a solar system,** you will need to know **the following:**

1. Estimated total requirements, in Btus or other units of measure, for the fuel you'd replace.
2. Cost per unit of the conventional fuels you're seeking to replace.
3. Total installed cost for the solar system.
4. Percentage of total annual requirements to be supplied by the solar system.

Estimated annual energy requirements should be readily available from existing plans or records, or from other information developed in your energy planning process. Check especially the Energy Management Form used to evaluate Buildings and the data collection sheets used to identify potential for Water Conservation, from those two sections of the *Planbook*. The cost per unit of the fuel you're seeking to replace should also be available from your earlier exercise in conservation planning, or from a quick check with the local utility or fuel dealer.

Total installed cost for the solar system can be estimated using the cost data presented above, together with the estimates of required collector size you made in going through the Production Potential section, above. You should also be able to estimate percentage of total annual requirements supplied by the solar system, as a result of estimating production potential.

Example 1: Installed Cost

Step One: Estimate the amount of conventional fuels and electricity to be replaced.

Example: A facility uses 19.48 MBtu or 5708 kwh electricity per year to heat hot water. A solar system will provide 70% of total requirements. 70% of 5708 is 3995 kwh = the amount of conventional fuels and electricity to be replaced.

Step two: Estimate the total annual savings obtained by installing solar.

Example: At the location in question, electricity is expensive, and costs $.06 per kwh. Multiply 3995 kwh by $.06 to give a savings of $239.70 per year.

Step three: Compute the simple payback period.

Example: Simple payback period, as used elsewhere in these planning materials, is computed by dividing the cost of the installation by the anticipated first year savings. In this case, it costs $1750 to install the solar hot water system. Divide $1750 by $239.70, to get a payback period of 7.3 years.

Example 2: Space Heat Only

Step one: The amount of conventional fuels to be replaced.

Example: The model home in Maryland uses 93.71 MBtu/year or 27,449 kwh. A solar system will provide 70% of total requirements. Seventy percent of 27,449 kwh is 19,214 kwh, the amount of electricity replaced by solar energy.

Step two: Determine the annual savings obtained by installing solar.

Example: Electricity costs are the same as in the first example, $0.06 per kwh. Therefore, the total savings for the first year is 19,214 x 0.06 =$1152.84.

Step three: Compute the simple payback period.

Example: Simple payback period is cost of installation divided by first year savings. The 980 ft^2 collector required for the sample house would cost an estimated $25 per square foot or a total of approximately $24,500. Simple payback would then be $24,500/1152.84 = 21.25 years.

Example 3: Hot Water plus Space Heat

Step one: The amount of conventional fuels to be replaced.

Example: The total Btu per year for the sample house is 106.20 Btu/year or 31,107 kwh/year. A solar system will provide 70% of total requirements. Seventy percent of 31,107 is 21,775 kwh, the amount of electricity replaced by solar energy.

Step two: Determine the annual savings obtained by installing solar.

Example: Electricity costs $0.06 per kwh. Therefore, the total first year savings is 21,775 x 0.06 = $1,306.50.

Step three: Compute the simple payback period.

Example: The total collector required is 980 ft^2 for space heat and 50 ft^2 for hot water or 1030 ft^2. It is estimated that 1030 ft^2 could be installed for $24 per square foot for a total of 1030 x 24 = $24,720. Simple payback is, therefore, $24,720 ÷ 1,306.50 or 18.9 years.

Example 4: Payback Period

At a 10% inflation rate (present rate is approximately 12%) the payback period for the previous three examples would be:

	Simple Payback Period	With 10% Inflation
For Hot Water Only	8.6	6.5
For Space Heat Only	21.25	12.0
For Both Hot Water & Space Heating	18.9	11.1

SOLAR THERMAL

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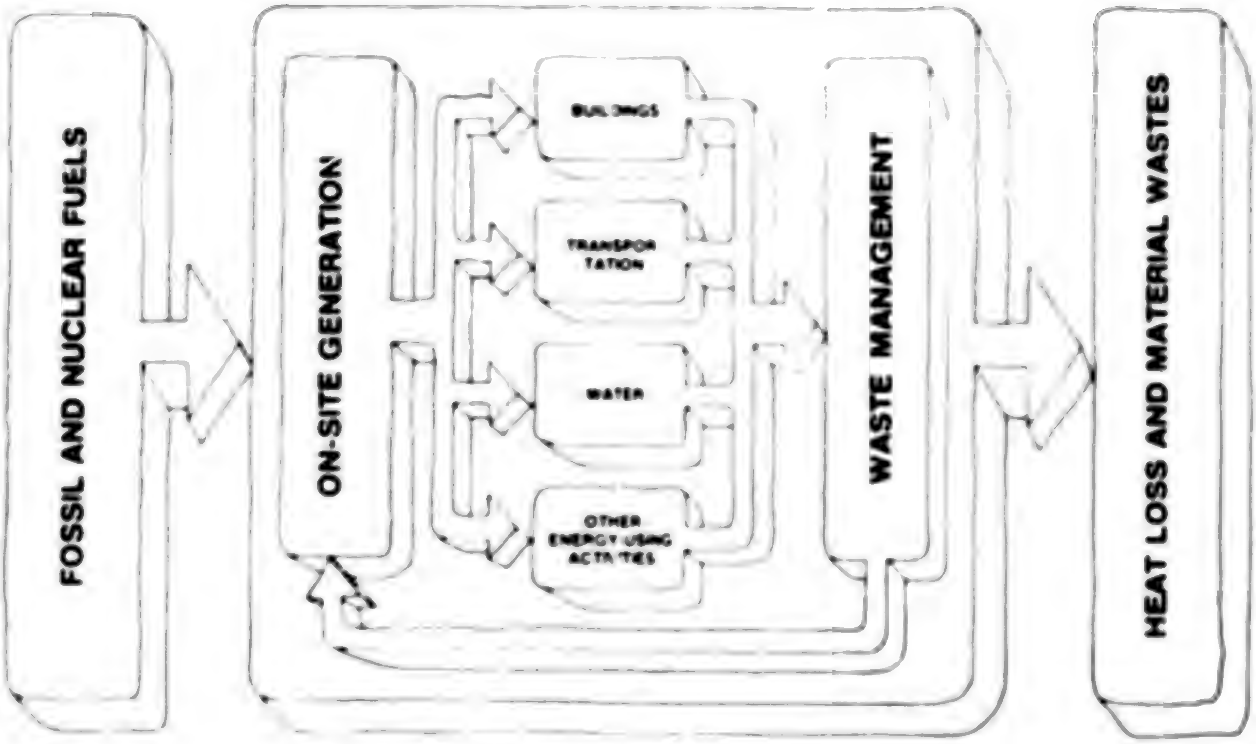
Biomass

SITE ENERGY-USING FUNCTIONS



BIOMASS

DEFINITIONS

Biomass is an alternative and renewable source of potential energy which can be processed into liquid and gaseous fuels. Bio means biological or living; mass means material. Biomass energy simply means harvesting living material for energy. It is a renewable form of energy because biological resources, when managed properly, can be harvested in such a way that they replace themselves at the same rate they are used. Biomass is a form of solar energy because plants are really natural solar systems that collect random solar radiation and use it to get nitrogen from the air and other minerals from the soil, and then organize them into new living material. There are many known and proven ways of converting biological resources directly into energy for people, the most fundamental of which is growing crops for food which powers our bodies.

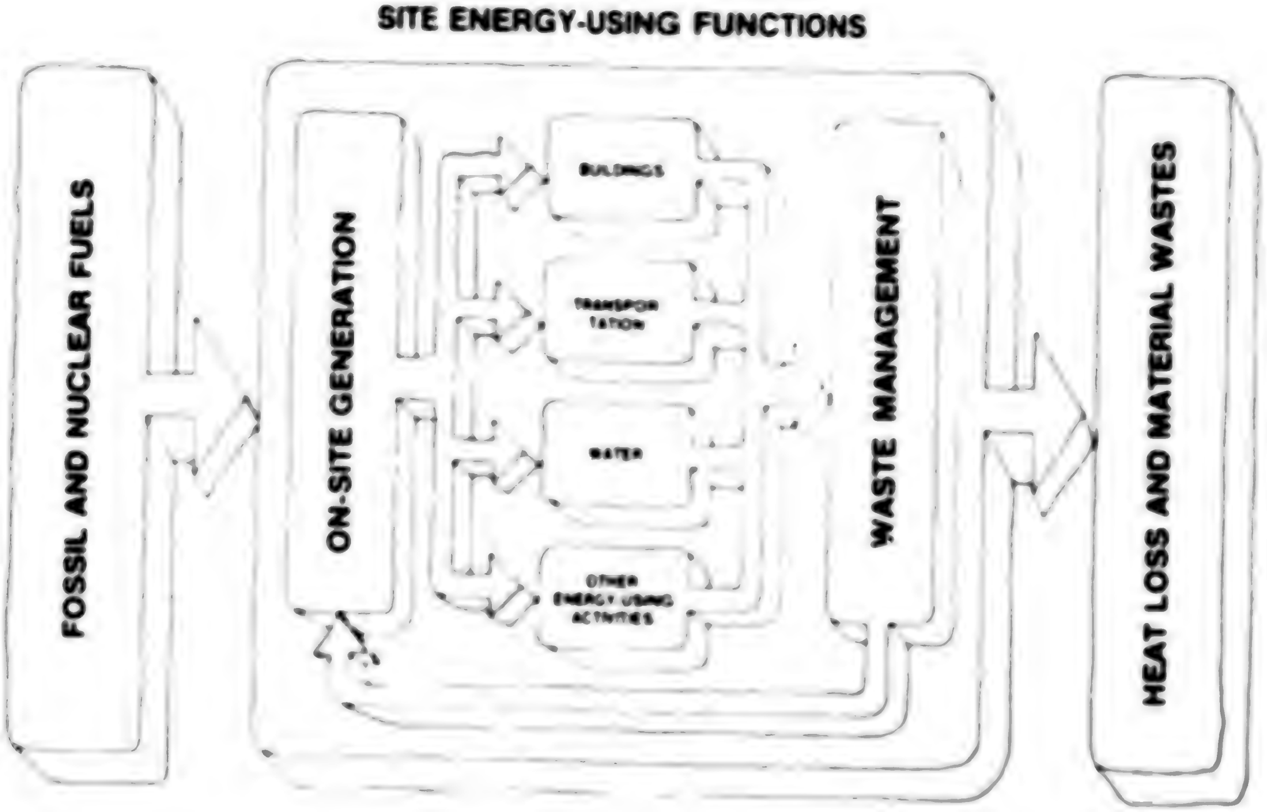
OUTLINE

To understand biomass energy, however, there are three aspects you must be familiar with:

1. Feedstocks or sources - These are the types of biological resources to be harvested.
2. Conversion technologies - There are many different techniques for converting feedstocks to useful forms.
3. Fuels - There are many types of solid, liquid, and gas fuels that are produced by the technologies.

To determine what combination of feedstock, technology, and fuel is most appropriate for your site, you must assess the local conditions, resources, and specific needs. The following material is divided into four basic parts. The subsections on Sources and Technologies introduce each basic type of biomass feedstock, technology, and fuel. The subsections on Anaerobic Digestion and Combustion focus on the two technologies most likely to be useful on a park or fish and wildlife site in more detail. They also discuss the most likely feedstocks and fuels for both digestion and combustion.

Biomass



SOURCES

BIOMASS

INTRODUCTION

The feedstocks for biomass conversion of living materials into usable fuels come from many varied sources. These sources differ in kind and in quality, depending on geographic concentration, energy content, and collectibility. Such sources will be examined and assessed in this subsection to offer information on both quality and quantity of their access for use at specific sites.

AQUACULTURE

Aquaculture is the growing of aquatic organisms under controlled conditions. It is a regenerative method of food and energy production if managed properly. Plant material harvested from aquaculture systems may be used as a feedstock for energy production.

Algae is a particularly productive aquatic crop. Under poor conditions, algae are from 2-5% efficient in converting energy from the sun into cellular chemical energy.(1) Under ideal conditions, they are from 20-30% efficient.(2) Forests are only about 1% efficient in the storage of solar energy. Algae grow and reproduce rapidly. Yields have been reported ranging from 10 to 20 grams per square meter per day or 14.4 to 32 tonnes per acre per year.(3)

The source of nutrients for an aquaculture system is an important factor in determining the cost of the system. Organic waste, particularly sewage, can play an important role in the system. Sewage provides a cheap source of nutrients for the algae while the algae perform the function of tertiary waste treatment.(4)

Conventional tertiary treatment commonly consists of chemical precipitation of phosphates and nitrates, and is a very expensive process. Conventional stabilization ponds in which sunlight, algae, and oxygen interact to restore water quality are not designed to optimize algae growth since they are designed to treat sewage. If algae growth is a recognized goal of the system, as for energy production, the design of these ponds would be modified. Conventional ponds are usually two meters (6.5 feet) deep and operate at a retention time of about 20 days. To maximize algae production, shallower depths of about .5 meter (1.6 feet) are required to allow sunlight to penetrate throughout, and shorter retention times (1.5 days) are desirable to keep nutrient levels high.(5)

Algae/sewage systems can serve as a new renewable energy source as well as a relatively inexpensive method of tertiary sewage treatment. A major constraint on algae/sewage systems is the amount of land required. Also, it may be more desirable to use the algae for animal feed rather than for energy production. On an area basis, the annual yield of algae may, under some conditions, be 127 times more productive than soybeans.(6) In livestock feeding tests, this protein was determined to be as digestible and efficient as other commonly used protein sources.(5)

The National Aeronautics and Space Administration has developed a process for treating sewage utilizing water hyacinths. The plant cleans up domestic waste water by absorbing nutrients and other chemicals in the sewage through its root system. When hyacinths are grown in warm enriched sewage, they produce from eight to 16 tons of plant material per acre per day (18-36 tonnes/ha). Further research will be required to make this process commercially available.

SOLID WASTE

Solid waste consists of materials that are either unusable or unwanted and that are usually disposed of by municipal services. Much of the solar and chemical energy that goes into the production of plants, animal material, and manufactured goods still remains in their solid waste. If this energy and materials could be reclaimed, it would represent a significant increase in the efficiency of our overall energy and material use.

In the U.S., more than two billion tons of organic wastes are generated each year, of which 160 million dry tons are collected urban and municipal solid wastes.(7) A study done in 1973 by the National League of Cities and the U.S. Conference of Mayors indicated that major U.S. cities are virtually being strangled in solid waste. The solid waste problem was particularly concentrated in high energy density cities, where the amounts of discarded solid wastes have doubled in the last 20 years compared with a nationwide doubling in the past 50 years.(7)

In many areas, industrial waste is not handled by municipal facilities and hence is not included in the solid waste figures. The separate treatment of industrial wastes is generally a good policy, because many of them are hazardous and require special handling. It is best to separate these wastes while they are relatively concentrated rather than to add them to the solid waste stream to be contaminated or serve as a contaminate for otherwise salvageable resources.

The need for a comprehensive energy and materials recovery system for solid waste is apparent. Such a system would ameliorate the present solid waste disposal problem as well as provide a short-term energy source. The energy supply from solid waste is expected to diminish as technologies improve for materials recovery. Potential problems involve decisions on the type of materials to be recycled and the method of their recovery as well as the trade-off between energy and materials recovery. Further information on types of waste and energy-conserving waste management systems may be found in the section on Waste Management in Volumn I, Reference Manual.

AGRICULTURE

Agriculture is the science of cultivating land for the raising of crops. Crops can serve as a source of nutrition for animals and humans and as a source of energy. The chief crops under cultivation in the U.S. are wheat, corn, hay, and soybeans. No crops are presently being grown specifically for their energy value.

Energy plantations are where crops for energy production are grown in high densities and over large land areas. Energy plantations are at the theoretical stage of development, although components necessary for their operation are commercially available today.(8) The U.S. is the leading country in development of this technology. One of the primary advocates of the concept is the Intertechnology Corporation, Warrenton, Virginia.(9) The Institute of Gas Technology, Chicago, Illinois, is also promoting the use of energy crops to provide synthetic natural gas.(10)

Since the technology involved in energy plantations has been proven,(11) the main technical problems relate to the choice of the best crop and the availability of suitable land. The type of crop selected depends on expected yield, its energy content, its adaptability to the physical constraints of the land, and the ease with which it can be grown, harvested, stored, and transported. Site suitability depends on water availability, soil characteristics, and the slope of the land.

Perennial plants are preferable to annuals as energy crops. Unlike annuals, perennials need not be replanted each year, and they can be harvested year round as needed to avoid major storage problems. Deciduous wood perennials are more desirable than conifers, because the young deciduous plants grow faster and can be harvested more often and with higher yields. Short rotation deciduous plants have an annual yield three times that of short rotation conifers.(12) Unlike conifers, many deciduous species such as poplars and cottonwoods will sprout vigorously from stumps and can be cloned. These properties make these deciduous species easier to manage by reducing planting and harvesting costs.

Perennial grasses can be harvested two to three times each year between frosts, thus having a higher annual yield than most deciduous woody plants. However, these higher yields may be offset by the higher harvesting and storage costs of the grasses. Grass crops need to be harvested all at once and within a short period of time to avoid spoilage. They also require special storage techniques for preservation purposes.

Energy plantations could provide a new labor-intensive renewable energy production industry which would decrease dependence on imported energy sources. More detailed research is needed in crop selection and site suitability to determine the location, extent, and type of crops involved in the energy plantation industry. The main question to be answered is whether to use available agricultural land for the cultivation of foodstuffs or for energy crops. (See Table 1.)

Table 1. Comparative Growth Rates of Various Crops (Source: References (13)-16))

Species	*Location*	*Organic Dry Tons/Acre/Yr*
Hemlock	*Oregon*	*11.0*
Red alder	*B.C. Coast*	*10.3-16.3*
Hybrid poplar	*Pennsylvania*	*4.0-8.0*
General Agriculture	*United States*	*3.0-16.0*
Reed canary grass	*Midwest U.S.*	*7.0*
Sugar cane	*Florida*	*17-22*
Cattails	*United States*	*20*
Hay	*United States*	*21*

WOOD

The U.S. is fortunate to possess forests which cover a vast land area. Forests have long been recognized as a valuable resource from aesthetic, environmental, and material perspectives. In the future, it is likely that they will be recognized as an important source of energy.

A tree serves as a biological solar collector which captures and stores sunlight through photosynthesis, by converting atmospheric carbon dioxide into cellulose and other complex, organic wood molecules. Because it is a type of solar energy, wood is a valuable source of renewable energy. This chemically trapped solar energy is used as fuel for fireplaces and stoves. Destructive distillation has been used to make methanol from wood. Pyrolysis converts wood chips, sawdust, and other wood wastes into energy intensive charcoal and oils.

Although part of the forests are harvested for timber, a significant percentage of the wood and wood residues is unused and could become an energy source. However, since some of this forest land is amidst residences or parkland, it is not all suitable for harvesting. The great potential for harvesting forest land in the U.S. is demonstrated by the fact that only 13% of the land is now industrially owned. (See Table 2.)

Table 2. U.S. Forest Land Acreage and Ownership by Region (1974) (Source: References (13)-(16))

	Northeast	Southeast	West	Total
Acreage (millions)	177.9	192.5	129.3	499.7
Federal	12.6	14.3	80.6	107.1
State and local	19.6	3.0	6.4	29.0
Industry	17.6	35.3	14.4	67.3
Farm	51.0	65.1	15.0	131.1
Private	77.4	74.8	12.8	165.1

The type and amount of wood available and accessible to forest lands are factors which affect the total forest yield. With proper management and harvesting of the forested areas and the use of complete tree harvesting, logging and mill residues, precommercial thinnings from commercial forest, and silviculture farms, the amount of wood and bark available for conversion to methanol is considerable.

In many forested areas of the U.S., the wood growth rate greatly exceeds the removal rate, and the forests are too dense and poorly managed. By harvesting the forests with intermediate cuttings such as cleaning, liberation cutting, and removing residues, the amount and volume of timber produced in a commercial stand would increase.(17) This kind of management would expose the mineral soil, aiding seed germination and reducing insect hazard (e.g., residues attract insects such as bark beetles). The National Research Council estimates that improved forest management techniques could double yields in the commercial forest presently being used.(18)

The initial harvest may be 20 times more than current yield when excess timber is cleared out. Excess timber includes unharvested dead and diseased trees or trees that have reached susceptible ages and have low vigor. With proper management, even the potential yield per hectare may increase to over 20 tonnes per year once high energy content species have been introduced. High energy tree species can trap up to 3% of the available solar radiation.

MARICULTURE

Seaweeds are macroscopic algae, usually found in the intertidal and shallow subtidal water of the world's oceans and seas. The edge of the sea is one of the best habitats for plant growth in temperate latitudes. In favorable circumstances, net primary productivity in seaweeds may be as high as the tropical rain forest.(19)

The ocean farming concept calls for the gathering and use of solar energy which is stored, by photosynthesis, in a seaweed crop. The harvesting and conversion of this renewable resource can make large new quantities of fuel energy available and conserve the limited fossil fuel reserves.

Mariculture has already been used in Japan, and a major facility is being planned off the California coast that could be adapted for use in other coastal areas by cultivating locally adapted species.(20) The seaweed would grow on rocks in shallow waters and on manmade supporting structures in the open sea. The crop would be harvested by specially designed ships, similar to those used by the Kelco Corporation to harvest kelp in California.

The supply of nitrogen is critical to the productivity of seaweed; it is more productive where it is enriched by sewage.(21) Polluted waters would thus comprise a natural source of fertilizer for seaweed. Over time, the seaweed would reduce the nitrogen content of these waters to normal levels, thereby reducing pollution and helping to restore the water for recreation purposes.

It has also been proposed that ocean farms could be fertilized by artificial upwelling of the nutrient-rich lower waters. Both the use of polluted waters and lower waters would enhance seaweed growth, but both fertilizer sources are problematical. For instance, using the nutrient upwelling would release perhaps three times as much carbon dioxide into the atmosphere as burning an equivalent amount of coal or oil.(22) It must be realized that both sewage and deep ocean nutrients are finite resources which would soon be exhausted in this use. It is therefore essential that the economy does not become dependent upon seaweed derived energy, but rather uses it only as a transitional source.

AGRICULTURE WASTE

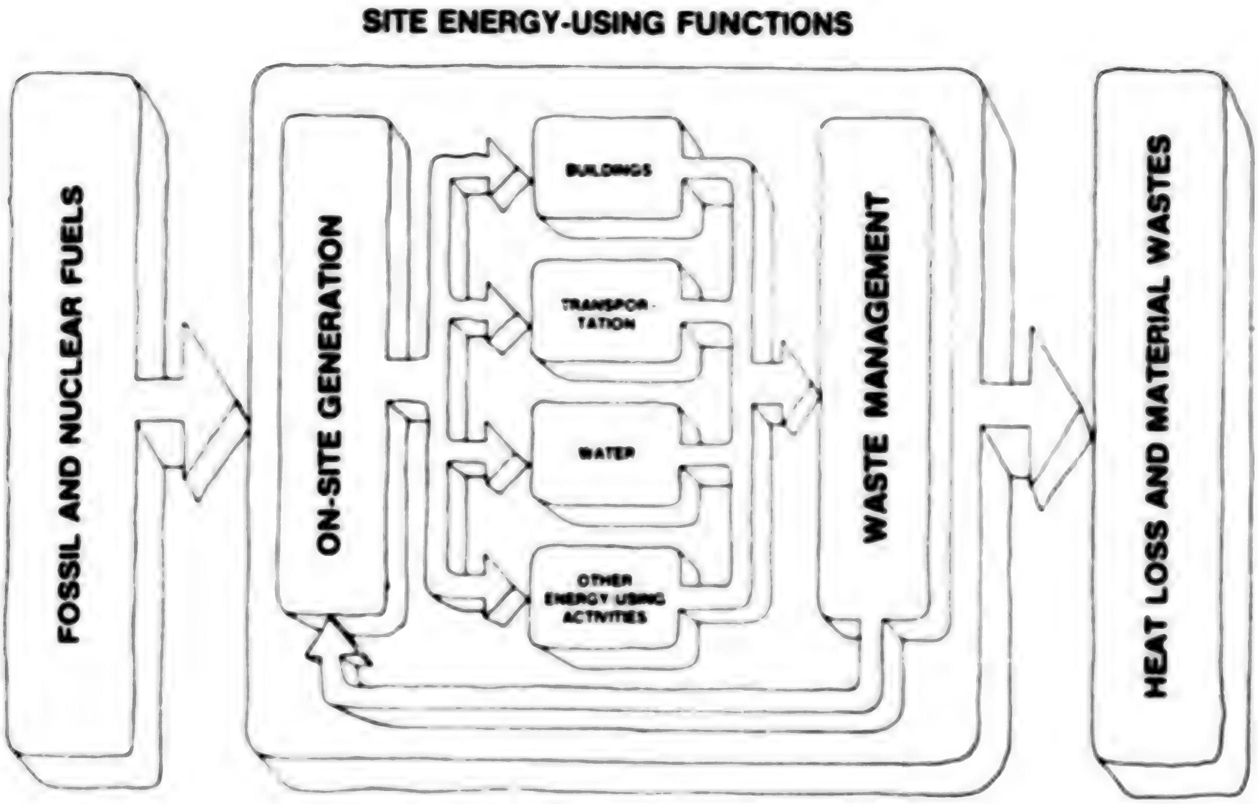
Agricultural residue is the portion of the crop considered unfit for human consumption. The residue can be utilized as mulch, bedding, or animal feed. It can be composted into fertilizer, or it can be used as a source of energy. Agricultural residue which remains unused is termed waste and is usually burned. The potential for the use of agricultural waste as an energy feedstock is particularly great in the midwestern U.S. (See Table 3.)

Table 3. Potential Energy in Agricultural Residue (Source: Reference (18))

		Million dry tons		Energy production	
Commodity	Acres (million)	Crop	Residue	Per acre (MBtu)	Total (Q)
Grains	158	215	303	45(25)*	7.1(3.9)*
Wheat	66	48	116	34	2.2
Corn	65	142	142	61	3.9
Oats	13	9	24	34	0.5
Sorghum	14	16	21	37	0.5
Green crops	74	153		29	2.2
Hay	61	117		27	1.7
Silage and sugarcane	13	36		39	0.5
Oilseed	68	41	34	18(6)*	1.2(0.4)*
Soybean	53	34	29	19	1.0
Peanut	2	2	< 1	21	< 0.1
Fruits and vegetables	9	13		20	0.2
Total	309	422	337	35	10.7

*Residue values in parentheses.

Biomass



TECHNOLOGIES

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BIOMASS

INTRODUCTION

In this subsection, the technologies used to convert biomass to usable energy from the sources described above will be examined and compared. Several alternative routes can be taken to convert the organic matter into energy, ranging from direct combustion for heat generation or electricity production to combustion in an oxygen free environment (pyrolysis) to produce more energy intensive fuels, to biological or chemical processing to produce alcohols. The alcohols can be used as replacements for present liquid fuels in transportation, heat generation, or electricity production depending on the characteristics of the source, the amount of feedstock available, and the form of energy desired. Each of the technologies that can be used to make these conversions from a chemical material to usable energy are described.

ANAEROBIC DIGESTION

Anaerobic digestion (or fermentation) utilizes bacteria in water and without oxygen to convert organic matter into usable products. These products include methane, sludge, carbon dioxide, traces of ammonia and hydrogen sulphide, and some additional bacteria.

The anaerobic digestion process has three stages. Stage 1 is the pretreatment of the digestible material. Stage 2 is the conversion. Stage 3 involves the separation and storage of the products (especially the gaseous components). The gases produced are stored in tanks. The slurry from the process is further separated into liquid and solid components. The liquid portion is usually drained out of the system as waste, but can be used as a medium for algae production or as an agricultural fertilizer. The solid portion can be partially recycled in the digestion system to increase bacterial concentration or used as a fertilizer or soil conditioner. The methane produced can be used as fuel for heating or producing electricity.(23)

There are several advantages of anaerobic digestion:

1. The process has been known for a long time.
2. It can utilize wet feedstocks.
3. It has low operating costs.
4. Capital costs are relatively low.
5. Energy requirements are low.
6. It produces easily collectible, energy dense synthetic natural gas.
7. Sludge can be used as fertilizer or soil conditioner.

The disadvantages of the technology are these:

1. There is a high degree of empiricism in design and operation of the digestor system.
2. Proper environmental conditions must be maintained for bacteria.(25)
3. The system requires skilled personnel for operation.
4. Required detention time is several days long.

See Table 4.

Table 4. Anaerobic Digestion Facts (Source: References (24) and (25))

Feedstock	*Wet biomass, manure, algae, waste liquors*
Energy Requirements	*Heat (30-60C)* *Electricity (for stirring and pumping)*
Additional Inputs	*Sludge (source of bacteria)*
Scale	*No fixed scales, but need stable supply*
Product	*CH_4 (about 60% of the gas produced)*
By-products & uses	*40% CO_2 used with methane in methanol synthesis or as a source of CO_2 to stimulate plant growth in*

	controlled environments
	NH3, H2S traces
	Sludge (for use as soil builder or fertilizer)
Capital Costs	*$0.0096 per kwh*
Operating Costs	*$0.017 per kwh*

The process of anaerobic digestion and its potential as a source for on-site generation of energy are discussed in more detail in the next subsection, Anaerobic Digestion.

PYROLYSIS

Pyrolysis is the breaking down of large organic compounds into simpler compounds and elements, using heat in the absence of oxygen. The destructive distillation of coal to produce oil and of wood to produce charcoal are familiar commercial applications of this process. Gaseous products are prevalent in high temperature pyrolysis while oil and tar are major products in a low temperature operation.

DESTRUCTIVE DISTILLATION (LOW TEMPERATURE PROCESS)

Destructive distillation is presently the primary chemical processing technique for wood. In this process, wood is heated in ovens in an inert atmosphere to temperatures of 160 to 430C to yield charcoal, wood tar, noncondensible gases, and a watery distillate called pyroligneous acid. Methanol, acetic acid, and acetone can be distilled from the acid.(26) Presently, the major product of the process is charcoal which is formed into barbeque briquets. The Nichols Engineering and Research Corporation uses a destructive distillation process to produce barbeque charcoal which yields both solid and gaseous fuels.(27)

The history of the use of destructive distillation is long. It was probably first discovered by early man when he observed and used the residual char in the ashes of his fire. The value of the char was recognized by the ancient Egyptians who employed it in their bronze metallurgy. They also used the tars produced for embalming. In the same period of history, another kind of tar was being produced from resinous woods in the Mediterranean area for use as a sealing material for wooden ships. The English immigrants brought the technology of pit charcoal manufacture to the New World settlements.

Charcoal was used as a fuel in U.S. iron furnaces from 1645 to 1840. The first U.S. plant with facilities for by-product recovery was established in 1830. As late as 1942, charcoal was a major domestic fuel in sections of New York City for heating and cooking in open braziers.

Destructive distillation of wood was the only commercial source of methanol until 1927.(28) The process was then replaced by methanol synthesis from the catalytic hydrogenation of carbon monoxide because this process is less expensive.(29)

Table 5. Destructive Distillation Facts (Source: References (26) and (29))

Feedstock	*Dry biomass, municipal waste, wood and farm residues*
Energy Required	*Heat (130-430C)*
Scale	*Small (18 to 36 tonnes/day)*
Product	*Methanol: CH3OH 7.0 to 7.5 kgs/cubic meter of hardwood*
By-products & uses	*75% of dry hardwood (by mass) is converted to charcoal use in metallurgical*

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processes, decoloring, etc.

7-9% of dry hardwood (by mass) is converted to acetic acid for use as vinegar

Tar, used as a fuel in the plant

CO, CO2, CH4, H2, NH3, H2S

Oils

The advantages of the destructive distillation process are:

1. The technology is well known.
2. By-products produced are valuable.

Disadvantages of the process are:

1. Feedstock is restricted.
2. Yield of methanol is low.
3. It is more expensive than the methanol synthesis process.
4. Widespread use of the process may produce large quantities of by-products for which no demand exists.

HIGH TEMPERATURE PYROLYSIS

High temperature pyrolysis is the thermal decomposition of large organic molecules into smaller molecules at high temperatures in the absence of oxygen. The process can be carried out in a fixed or moving bed reactor. The material to be pyrolized is introduced into the reactor by means of gas entrainment or mechanical transport by hopper or worm screw. Heat is supplied to the feedstock by contact with hot gases or with solid particles in a fluidized bed. The products of pyrolysis include char, tar, oils, water, ammonium sulphate, and gases. The gases are mainly hydrogen, carbon monoxide, and carbon dioxide.

The technology of pyrolysis is well developed. Both fluidized-bed pyrolysis and flashing pyrolysis have been carried out in small scale reactors. Existing plants for the pyrolysis of municipal waste range in size from a 1.8 tonne per day pilot plant in Santa Ana, California, to a 900 tonne per day plant under construction in Baltimore, Maryland.(30)

One of the major problem areas in pyrolysis technology is how to incorporate scaling factors in design. The cost of the plant in dollars per tonne per day decreases with increasing plant capacity, as do operating costs in general. Thus, pyrolysis plants with capacities of 2,000 to 20,000 tons (1,800 to 18,000 tonnes) per day are being planned.(31)

The advantages of high temperature pyrolysis include: (32)(33)

1. Well developed technology,
2. Low operating costs,
3. Capital investment comparable to incineration,
4. Land requirements no more than required for incinerator,
5. Accepts various feedstocks,
6. Can reduce volume of solid waste by 90%,
7. Type of by-products can be controlled, and
8. Reaction time is fast (minutes).

Disadvantages of high-temperature pyrolysis include: (33)

1. Requires dry feedstock,
2. Feedstock must be shredded to optimize gas production,
3. Syngas yield is lower than that obtained from gasification,
4. Lower energy efficiency than with anaerobic digestion,(48)
5. Best suited to large scale plants,
6. Generates large amount of waste heat(49) (however, this could be an advantage if used in a cogeneration system), and
7. Widespread use of the process may produce large quantities of by-products for which no demand exists.

See Tables 6 and 7.

*Table 6. Typical Products of Flash Pyrolysis**
(Source: Reference (27))

Char	*20%*	*5.31 Mwh/tonne*
Oil	*40%*	*6.83 Mwh/tonne*
Gas	*30%*	*3.92 Mwh/tonne*

Gas Composition: (mole %)

Hydrogen	*12*
Carbon monoxide	*37*
Carbon dioxide	*37*
Methane	*6*
Ethylene	*3*
Ethane	*1*
C3	*1*
C4+	*2*
Hydrogen sulphide	*0.8*
Hydrochloric acid	*0.2*
TOTAL	*100*

Water	*10%*
TOTAL	*100%*

**Municipal refuse feed, yield at 500C based on dry mass of feedstock.*

GASIFICATION

Gasification is a partial oxidation process involving the conversion of the energy content of the organic component of the feedstock into a useful gaseous form. The product gas may then be used as a fuel or as a chemical raw material.

Several types of gasifiers have been developed for the gasification of wood and municipal refuse. Unlike coal gasifiers, these are designed to operate at atmospheric pressure. Partial oxidation is carried out using either air(37) (Batelle, Carborundum Corp.), air and steam(38) (Moore-Canada), or oxygen(39) (Union Carbide). With air or air and steam, the resulting crude gas contains about 40-50% nitrogen, and with oxygen, the nitrogen component is less than 1% and the gas has a higher enthalpy.(40) In all cases, the gas has a large water vapor content due to the moisture already present in the feedstock and the additional vapor generated during gasification.

Union Carbide Corporation has developed a gasification process (Purox) for the partial oxidation of "as is" municipal solid waste using oxygen as the oxidizing medium. The term "as is" refers to feedstock with particle sizes ranging from sawdust to multicentimeter length chunks with a moisture content of 30-50%.(39)

The feedstock is injected into a shaft furnace which employs a moving bed through which oxygen is passed countercurrent to the down-flowing residue. As the material descends through the reactor-gasifier, it passes successively through drying, reduction, and oxidation stages until it deposits as a molten slag or ash at the furnace bottom.

The Purox system has been tested in

Table 7. High Temperature Pyrolysis Facts (Source: References (34) - (36)

Feedstock	Dry biomass, municipal waste, wood and farm residue	
Energy required	Heat (870C or more) Electricity for feeder	
Production rates	Pyrotech (Santa Ana)	1.8 tonnes per day
	Garrett R&D Company	3.6 tonnes per day
	Carborundum Env. Systems, Inc.	70 tonnes per day
	Devco Management Company	150 tonnes per day
	Occidental Research Company	180 tonnes per day
	Monsanto Langard (Baltimore)	900 tonnes per day
Product	Synthesis gas: CO, H2	
By-products & uses	From 1 tonne of municipal waste pyrolyzed at 870C	
	Gas:	560 cubic meters which can be used as a low sulphur fuel with a heating content of 2.8-4.5 kwh per cubic meters primarily H2, CO, CO2, CH4, C2H4
	Liquid:	475 litres which can be used as a gas preserver or an insecticide. The liquid is 90% water and 10% organic compounds.
	Char:	77 kgs which can be used as a fuel with 3.3-5.56 Mwh per tonne
	Tar:	.5 gallons which can be used as a fuel
Capital costs	$0.0021 per kwh $4,500,000 for a 200 tonne per day plant	
Operating Costs	$0.0168 per kwh $550,000 per year for a 200 tonne per day plant	

a 4.5 tonne per day plant in Tarrytown, New York (1970) and in an 180 tonne per day plant in Charlestown, West Virginia (1974).(41) Currently, the Tarrytown unit has been replaced by a nine tonne per day unit at Tonawanda, New York.(42) Scale-up of the reactor to a 3.5 meter movable bed for the 180 tonne per day plant resulted in a significant decrease in the conversion efficiency as evidenced by an increase in carbon dioxide and hydrocarbon levels in the raw gas.(43) An important factor in a moving bed reactor is the stability of the bed; the stability apparently decreases with increasing bed diameter. This, as well as the Lurgi systems failure to operate a four meter diameter bed, casts doubts on the possible scale-up of Purox beyond 3.5 meters.(43) Union Carbide expects to market the process in 320 tonne per day modular units.*(44)

Although the Purox process has only been tested on municipal solid waste thus far, the assumption that gas composition and yields for the process will not change when the feedstock is wood appears to be conservative.(44)

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*Telephone conversation, NE Lindy Division, Union Carbide, August 2, 1977.

Advantages of the gasification process are:

1. Utilizes versatile feedstocks,
2. Produces highest yield of synthesis gas,
3. Produces by-products that are valuable resources, e.g., fused grit for roads,
4. Comprises small to medium scale technology, and
5. Emits relatively clean stack emissions since NOx and SOx content is negligible.(45)

Disadvantages of gasification include:

1. Large capital investment,
2. High operation and maintenance costs,
3. Skilled labor requirement,
4. Syngas yield depends on precision with which operation is controlled, and
5. Temperature and amount of the water by-product may be environmental hazards.

See Tables 8 and 9.

HYDROLYSIS

Hydrolysis is a chemical reaction involving the decomposition of a compound and the addition of water to its resultant by-products. Ethanol can be obtained from cellulose by either acid or enzymatic hydrolysis and subsequent fermentation of the glucose to ethanol.

Acid hydrolysis involves the treatment of cellulose with strong hydrochloric acid or dilute sulphuric acid to form a lignin residue and a liquor containing sugars, organic acids, and other organic compounds. Enzyme hydrolysis is essentially the same chemical process as acid hydrolysis except that a biological rather than a chemical catalyst is used. The sugars generated by hydrolysis can be processed into a molasses-type animal food, yeast (torula strain), polyols, and ethanol.(49) The lignin residue can be used as fuel or converted to phenols, oils, or activated charcoal.(50)

There are several advantages in the use of enzymes to hydrolyze cellulose instead of acid.

> When using acid, expensive corrosion-proof equipment is required. Moreover, the crystalline structure of cellulose makes it very resistant to acid so that temperature and acid concentration needed to achieve hydrolysis also cause decomposition of the resulting sugars. Consequently, the process must be balanced so that the rate of hydrolysis must be sufficiently high to compensate for the decomposition of the desired products. Waste cellulose invariably

Table 8. Dry Basis Crude Gas Compositions (Source: Reference (46))

Raw Gas	*Moore Canada**	*U.C.C. Purox***
Hydrogen	*18.3%*	*26.0%*
Carbon monoxide	*22.8*	*40.0*
Carbon dioxide	*9.2*	*23.0*
Methane	*2.5*	*5.0*
Hydrocarbons	*0.9*	*5.0*
Oxygen	*0.5*	*0.5*
Nitrogen	*45.8*	*0.5*
TOTAL	*100%*	*100%*

**Data are from wood waste in volume percentage.*
***Data are from garbage in volume percentage.*

Table 9. Partial Oxidation Fact Sheets (Purox)
(Source: References (39), (47), and (48))

Feedstock	*Biomass with moisture content less than 50%*	
	Municipal waste, wood, farm residue	
Energy required	*Heat 200-1700C*	
	Electricity for compressors, precipitators, condensors, etc.	
Additional inputs	*.37 tonnes of oxygen per tonne of feedstock*	
	MEA, a carbon dioxide absorbing chemical	
Production rates	*Purox, Tarrytown, N.Y.*	*4.5 wet tonnes/day*
	Purox, S. Charlestown, W.Va.	*180 wet tonnes/day*
		650 wet tonnes/day
Product (by volume)	*CO*	*40%*
	H2	*26*
	CO2	*23*
	CH4	*5*
	CxHy	*5*
	N2	*1*
By-Products & uses	*water vapor*	*.51 tonne/tonne dry feedstock*
	ash/slag	*.04 tonne/tonne dry feedstock*
	which can be used as a road builder or land-fill	
	oils, a small amount which returns to the gasifier	
Capital costs	*$59.5 million for a 1,000 tonne/day plant*	
Operating costs	*$44.72 per tonne (including methanol synthesis, excluding cost of feedstock)*	

contains impurities which will react with the acid, thereby producing unwanted by-products and reversion compounds. The enzyme, however, is specific for cellulose and does not react with impurities present in the waste.(51)

However, acid hydrolysis is a well developed technology while enzymatic hydrolysis is still in the developmental stages.

CATALYTIC HYDROGENATION

Catalytic hydrogenation is the process presently used for converting synthesis gas into methanol. Essentially, the same process can be used to manufacture ammonia, methane, and higher hydrocarbon chains. The only difference is in the catalyst necessary to produce the desired end product.(52) The process works because pressure favors a physical change where the volume of the products is less than the volume of the reactants. In the synthesis of methanol from carbon monoxide and hydrogen, one volume of carbon monoxide reacts with two volumes of hydrogen under pressure and heat to produce one volume of methanol.

Although usually a high pressure process, it has been found that by varying the catalyst, hydrogenation can occur at various temperatures and pressures. These range from .5 million kilograms per square meter (I.C.I.* process), to 2.5 million kilograms per square meter (Vulcan Cincinnati process), to 3.5 million kilograms per square meter (high pressure process).(53)

The process consists of two main stages. In the first stage, the ratio of the synthesis gas components is altered to give the required carbon monoxide ratio of one to two. The actual synthesis occurs in the second stage.

There are four substages to the initial reforming stage. First, the syngas passes through a shift converter where carbon monoxide is reacted with water to give hydrogen and carbon dioxide. This helps to decrease the hydrogen deficit. The second substage is in the reformer where hydrocarbons are reacted with water to give carbon monoxide and hydrogen, again increasing the available hydrogen. In the third substage, condensate separation occurs (removal of water vapor). Finally, carbon dioxide is absorbed.

The synthesis stage consists of five substages. First, the gas is compressed. Next, the actual synthesis occurs. The synthesis reaction is exothermic which means it gives off heat. This heat is used within the process. The third substage is the recycling of unreacted feedstocks into another compressor, the circulator compressor. It is then mixed with the feed gas from the first compressor to pass through the synthesis reactor again. That part of the feedstock which was reacted goes to the flash drums where the water vapor is removed. The final stage of the synthesis is the storage of the methanol.

Methanol yields from catalytic hydrogenation can be increased by 50% if small amounts of other alcohols are tolerable in the product.(54) Such a mixture is called methyl fuel, and it contains more energy than chemical grade methanol due to the presence of ethanol, propanol, and isobutanol. These higher alcohols give the methyl fuel another advantage in helping to prevent cold start problems in engine combustion. In a conventional methanol plant, these alcohols are treated as contaminants and are removed by the distillation processes. If these processes were omitted, capital and operating costs would be reduced.

At present, methyl fuel is not being manufactured because no demand exists. However, modification of the I.C.I. process to produce methyl fuel would not be a major problem.(55) Research is needed to optimize the design for methyl fuel production and to develop integrated gasification and catalytic hydrogenation systems. As yet, no such prototypes have been developed. (See Tables 10 and 11.)

POSSIBLE ALTERNATIVES

Fermentation

Methanol is found in plants and animals, and bacteria do exist which consume methanol. Thus, it is conceivable that a bacterium may exist which can decompose complex organic compounds into methanol in much the same way that glucose is fermented to ethanol. To date, however, no such process has been developed.

Synthesis from Carbon Oxides

It has been suggested that methanol could be synthesized from carbonate solution or dissolved carbon dioxide by the use of radiation or electroreduction.(57) Carbon dioxide can be split into carbon monoxide and oxygen by the use of radiation. The carbon monoxide is then reacted with water via the water gas shift reaction to form syngas. The syngas is then converted to methanol by catalytic hydrogenation.

Very selective catalysts and unusual conditions may be required to produce methanol directly. However, a two stage electrosynthesis (carbon dioxide to formates and formic acid to methanol) may be a practical route to methanol, particularly where inexpensive electricity is available.

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*Imperial Chemical Industries

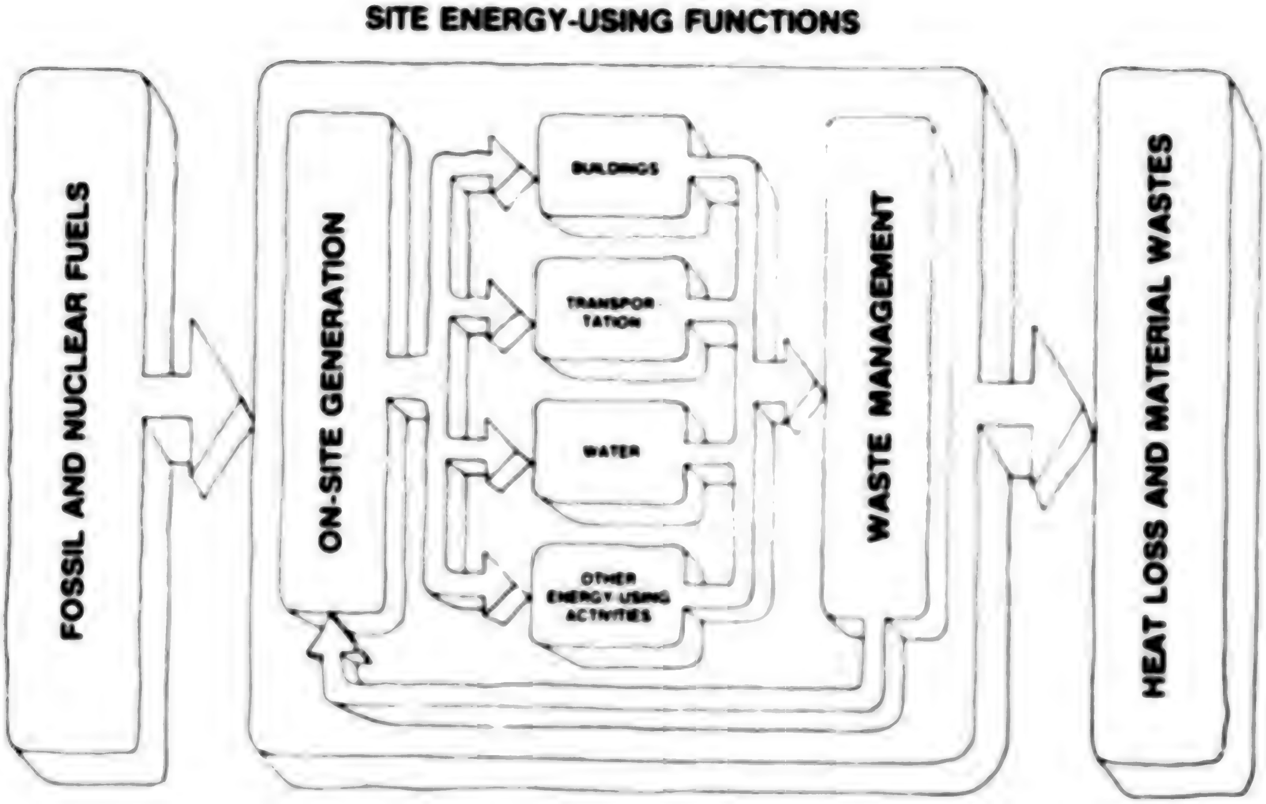
Table 10. High Pressure Hydrogenation Facts
(Source: Reference (54))

Catalyst	CrOx,ZnOx
Energy required	Heat 330-390C Electricity - 510kwh per tonne methanol
Additional inputs	Heat remover (cooling water) chemicals for methanol purification
Production rates	550 to 1800 tonnes or more due to the type of centrifugal compressor used
Minimum production rate	450 tonnes per day due to the type of centrifugal compressor used
Product	Methyl fuel
By-products & uses	5.5 mole % in product gas acetones aldehydes amines di-methyl ether ethanol higher alcohols heat

Table 11. Low Pressure Hydrogenation (ICI) Facts (Source: Reference (56))

Feedstock	Naptha or CH4 and CO2 or CO and H2 or Crude petroleum or Coal or Coke (#)
Catalyst	Copper based
Energy required	Heat 250C-270C Electricity 300 kwh per tonne
Additional inputs	Heat remover (cooling water) Chemicals for methanol purification
Scale	ICI is especially adapted to below 450 tonnes per day although larger plants may be possible
Production rates	Chang Chun Petro-chemical Company 135 tonnes/day Monsanto Chemical Company 900 tonnes/day
Minimum production rate	Less than 135 tonnes per day
Product	75-90% methanol
By-products	2.5 mole % in product gas Acetone Aldehydes Amines Di-methyl ether Ethanol Higher alcohols
Costs	Less than for high pressure process

Biomass



ANAEROBIC DIGESTION

BIOMASS

INTRODUCTION

Anaerobic digestion is the conversion of organic matter to methane by fermentation. The process is carried out by bacteria in the presence of water and in the absence of oxygen. The main products of the process are methane, sludge, and carbon dioxide. Traces of ammonia and hydrogen sulphide and some additional bacteria are also produced. The gaseous component of the product is commonly referred to as biogas. The energy from the biogas is entirely due to the energy content of the methane.

Any organic matter with the proper nutrient balance for the bacteria and which can be digested by the bacteria is an appropriate raw material for the digester. Sewage and manure are likely to be the most suitable feedstocks available in national parks, wildlife refuges, and hatcheries. These wastes have a suitable nutrient composition and can be easily decomposed by the bacteria. Agricultural or kitchen wastes (e.g., paper, vegetable, and meat scraps) may also be added to the digester provided that the lignin (the rigid, woody structure of plants) content of the waste is small. Bacteria find lignin almost impossible to break down.

Although it has been demonstrated that digesters can operate effectively utilizing solid waste as an input,(23) it is not recommended as a feedstock for digestion. Separation of the organic from the inorganic component of the waste poses problems, and it may be difficult to obtain solid waste with a consistent content over time and the necessary nutrients for the bacteria.

HISTORY

The production of methane by anaerobic digestion is a naturally occurring biological process. It was discovered in the 17th century after scientists observed the so-called marsh gas burning on the surface of swamps. Today, anaerobic digestion is widely used for the controlled degradation of sewage solids. For example, since 1950 the Hyperion sewage treatment plant in Los Angeles, California, has been using the methane generated from its plant as a fuel to power the plant and has been selling the surplus to the municipal electrical generating facility.(23) Many European farmers, particularly in France and Germany during and after World War II, used digesters. Thousands of Asian farmers are currently using the process to produce their own energy. In China alone, over four million biogas plants have been built to supply fuel for lighting, cooking and heating from human excreta, animal feces, crop stalks,and water.(58)

TECHNOLOGY

There are two main types of anaerobic digesters, batch-loaded and continuously loaded digesters. Meynell(59) has broken down these two groups further. For a comparison of these systems, see Table 12.

Batch-loaded digesters start empty and then are completely loaded. Gas production begins, peaks and declines slowly to near zero before the batch is emptied and the cycle is repeated. This type of digester does not produce biogas at full capacity for most of the cycle.

Continuous-loaded digesters are designed to operate at peak capacity all the time. In most situations, however, it is impractical to load the digester more than once per day. The continuous-loaded digester is suitable for most applications. The batch-loaded digester is more appropriate for inputs containing large lumps of organic matter which can block the flow pipes of a continuous-loaded digester, for inputs which are only available at irregular intervals or for organic material which is difficult to digest.

The digestion process can be divided into three main stages. (See Figure 1.)

Table 12. Comparison of Anaerobic Digestion Systems
(Source: Reference (59))

Type of Digester	Batch	Plug-flow	Conventional sewage works	High rate	Anaerobic contact
Suitable Wastes	Agricultural Irregular Fibrous or difficult to digest	Agricultural continuous or regular flows. Less fiber content	Continuous sewage sludge	Agricultural Industrial	Industrial Agricultural
Volumes, solids content	Low volumes up to 25% solid	Larger volumes 5-15% solids	Less than 5% solids	4-15% solids	Low solids
Typical Retention times	60 days or more	30-60 days	30-60 days	5-20 days	0.5-5 days
Degree of mixing	Little needed	Occasional	Occasional	Continuous	Continuous
Operating Temperatures	Usually 30-35°C	30-35°C	30-35°C or unheated	30-35°C	30-35°C
Gas Production	Irregular and discontinuous	Continuous	Continuous	Continuous	Continuous
Degree of control required	Little once started	Simple	Simple	More Complex	Complex
Comments	Messy and time consuming to start	Loading and scum removal can be messy	Not very effective	Can be automated	Automatic

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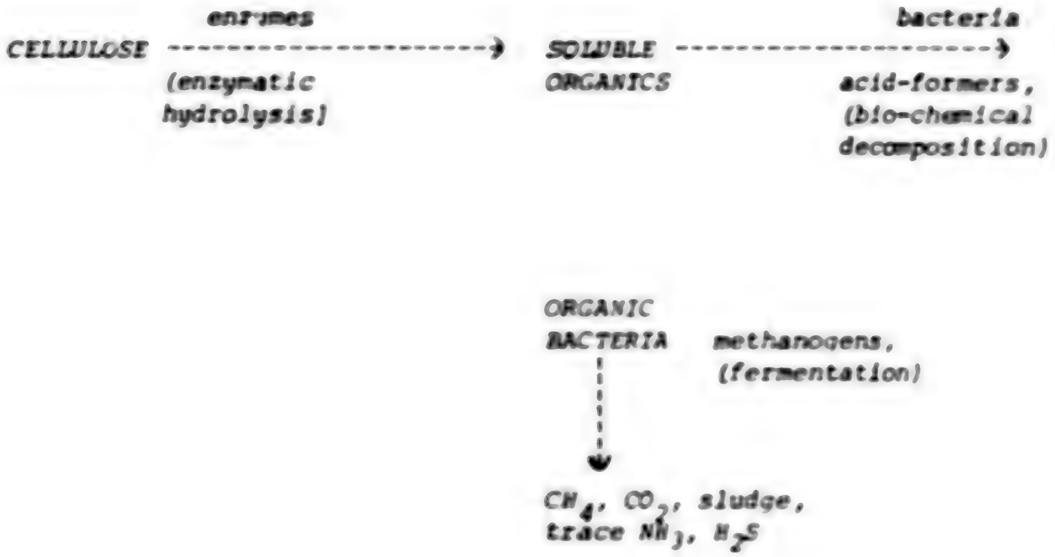
Process Stages


enzymes
CELLULOSE
(enzymatic hydrolysis)
SOLUBLE ORGANICS
bacteria
acid-formers, (bio-chemical decomposition)
ORGANIC BACTERIA
methanogens, (fermentation)
CH4, CO2, sludge, trace NH3, H2S

Overall Process

$$C_6H_{10}O_5 \xrightarrow{\text{bacteria}} 3\ CH_4 + 3\ CO_2 + \text{new bacterial growth}$$

Figure 1. Process Stages and the Overall Process of Anaerobic Digestion (Source: Reference (24))

The first stage involves the pretreatment of the organic material. This may include shredding, dilution, mixing and balancing of the nutrient composition of the feedstock. Next, the conversion of the organic matter to gas and new bacteria takes place in an airtight tank - the digester. The contents of the tank may be heated and stirred occasionally to increase the rate of gas production. The stirring not only releases the gas for collection by breaking the scum layer but also mixes some bacteria into the incoming material. This reduces the time needed for methane to start being formed. The final stage of the process involves the separation of the products and the storage of the gas produced. The product gas is stored in tanks. Depending upon the end-use of the gas, it may require further separation into its components. The solid-liquid slurry is removed from the digester and placed in a separation tank. The solids may then be partially recycled to the digester to increase its bacterial concentration, with the remainder being used as a fertilizer or soil builder. The liquid portion is usually drained out of the system, but has been used as a medium for algae production or as a fertilizer for forests and orchards.

A number of environmental factors affect the anaerobic digestion process. Among the controlling influences are the nutrient composition of the inputs, pH (acidity or alkalinity), temperature, digester design, and mode of operation.

Like all living organisms, bacteria require essential nutrients to sustain life. The major nutrients required by the bacteria are carbon, nitrogen, phosphorous, and sulphur. Excessive levels of these or other substances may poison the bacteria. Small digesters are far more susceptible to sudden changes and to shock loadings of toxic material than are large digesters. This stresses the need for a regular consistent feedstock with constant environmental conditions in the digester.

A successful pH range for anaerobic digestion is 6.0 to 8.0. Digestor failure occurs when the pH is too low, resulting in a build-up of acids, a decrease in methane, and an increase in carbon dioxide production. Therefore, careful monitoring of the digester is required to produce a high yield of methane.

One of the most important environmental considerations which influences the rate of methane production is temperature. It has been found empirically that the optimum temperature range for digestion is between 86°F and 96°F, as it combines the best conditions for the growth of the bacteria and the production of methane with the shortest retention time. Under certain conditions, however, the optimum range may be inappropriate from a net energy standpoint, particularly in areas which experience long severe winters. Pilot plant experiments done at the University of Manitoba, Canada, have demonstrated the feasibility of anaerobic digestion of swine manure at temperatures between 68°F and 77°F.(60) Gas production and gas quality in addition to other parameters indicate that the process is favorable at these lower temperatures. More research is needed on cold temperature digestion, but the work done at the University of Manitoba has made anaerobic digestion in cold climates more promising.

Safety is a major consideration in the construction, operation, and maintenance of a digester. Methane is flammable, and under certain conditions it may be explosive. Therefore, safety precautions are needed to prevent ignition in all areas of production, handling, storage, and utilization of the biogas. Standards which apply in the natural gas industry can serve as useful guidelines for a digester installation. Advice from persons knowledgeable in the handling of natural gas may be useful when the system is being designed and built.

The nature of anaerobic fermentation is not completely understood. Despite widespread use of the process to stabilize municipal sewage, the optimum process performance with respect to gas production is seldom achieved because of the high degree of empiricism that still prevails in the design and operation of the system.(24) One of the greatest problems with the technology is the early detection of the impending process failure so that proper control measures to prevent it can be taken.(61)

D. ADVANTAGES/DISADVANTAGES

There are several advantages of anaerobic digestion:

1. Process known for a long time,
2. Can utilize wet feedstocks,
3. Low operating costs,
4. Relatively low capital costs,
5. Low energy requirements,
6. Produces easily collectible, energy dense synthetic natural gas, and
7. Sludge can be used as fertilizer or soil conditioner.

The disadvantages of the technology include:

1. High degree of empiricism in design and operation of the digester system,
2. Requirement for maintenance of proper environmental conditions for bacteria, especially the sensitive methane producing bacteria (pH temperature, C:N=30:1),(25)
3. Requirement for skilled personnel for operation of the system,
4. Length of detention time (several days),(25) and
5. Concern about safety.

E. ASSESSING SUITABILITY

In order to make a preliminary assessment of the suitability of anaerobic digestion at your site, it is essential that you do the following:

1. Ascertain the demand for biogas at your site. There is no point in producing a fuel which cannot be utilized.
2. Determine how much of your energy demand can be met by biogas. The amount of biogas that can be produced is largely dependent upon the amount of suitable organic material available.
3. Determine the economic viability of an anaerobic digestion system at your site. This will depend upon the capital and operating costs of the digester, the amount of usable biogas which is produced, the cost of the fuel which the biogas is displacing, plus the advantages provided by digestion as a waste treatment system.

1. Energy Demand for Biogas

Before deciding to produce biogas by anaerobic digestion, you must first find out if the biogas produced can be put to good use. An inventory of your current energy uses and the type of fuel being employed for each use will help you to assess which uses can be fueled by biogas without major modifications to existing equipment and which uses require new equipment more suited to employing a gas as a fuel. A careful look at Table 13 will tell you the appropriateness of biogas for various purposes. Table 14 will give you an idea of the energy conversion efficiencies involved in various end uses of the biogas. Table 15 presents a biomass demand chart for comparison of the rate of use of conventional and biogas fuels.

Table 13. Uses of Biogas

Use	Biogas ft^3	Methane ft^3	Rate
Lighting	4.0	2.5	per mantle/hour
Cooking	13 - 26	8 - 16	per hour per 2 4" burners
Cooking	19 - 24	12 - 15	per person per day
Gas Refrigerator	2.0	1.2	per hour per ft^3 of refrigerator space
Domestic Central Heating	67 - 208	41 - 129	per hour
Direct Heating	15 - 31	9.5 - 19	per hour
Gasoline Engine	16	11	per brake horsepower per hour
For Gasoline	180 - 250	150 - 188	per gallon
For Diesel Oil	200 - 278	150 - 188	per gallon

Table 14. Conversion Efficiencies

Conversion Process	*Energy Efficiency*
*Biomass to Biogas**	40% - 70%
Biogas to Heat	75%
Biogas to Heat to Mechanical	25% - 40%
*Biomass to Biogas to Electricity***	0.02% - 0.5%

* Does not include process heat
** Does not include cogeneration

Table 15. Biomass Demand Chart

Energy Use	*Present Fuel*	*Rate of Energy Use of Present Fuel*	*Rate of Use of Biogas*
Space Heating			
Water heating			
Etc.			

Biogas is more suitable to certain end uses than to others. If the biogas is to be burned directly for cooking, space heating, or water heating, or for use as a fuel for a stationary internal combustion engine for space heating or electricity generation, it is doubtful that the removal of the carbon dioxide component of the biogas can be justified.(62) Although it has no energy value, the carbon dioxide is not harmful to mechanical equipment. However, the use of biogas as a fuel for cars, trucks, and other transportation vehicles may be impractical unless the carbon dioxide is removed.(63) The removal of the hydrogen sulphide from the biogas may be necessary to prevent corrosion.

Energy Supply of Biogas

Now that you have determined the appropriate uses for the biogas, it is time to find out how much energy you can produce. This will largely depend upon the total amount of suitable organic material available for digestion.

The availability of the raw material is primarily due to the ease with which it can be collected. This is a function of the concentration of the feedstock near the site of the digester. The period of time over which the organic matter is generated is also an important consideration. If most of the input is produced during one season, it is likely that the organics will have to be stockpiled for a period of time. The longer the feedstock is stockpiled, the more decomposition will take place and the smaller will be the yield of biogas. In this case a batch-loaded digester may be most appropriate. On the other hand, if sufficient organic material is available daily or weekly, a continuous-feed digester may be the choice.

Sewage is likely to be the most suitable and most readily available feedstock for a digester. Organic refuse which can be easily digested by the bacteria can also be added to the sewage to increase the carbon content of the feedstock and thereby, improve the carbon:nitrogen balance. Newspaper, paper bags and other large items require shredding and must be well mixed in the digester.

Manure from livestock operations nearby may also be appropriate. As with the other feedstocks, the suitability of the manure will depend upon the hauling distance from the source to the digester. If a long distance is involved, the transportation costs may outweigh the benefits of the additional energy production. Once the type of available feedstock is known the next step is to determine the amount of energy that the organic material can yield. Table 16 tells you how much energy can be produced from the excrement of various animals in one day. It also says how much energy can be obtained from one pound of garbage. From this information, you can compute how much energy per year can be produced.

The following equations will enable you to calculate the total amount of energy available per year from either sewage or animal manure.

Animal Waste Energy/year = Energy/Animal/Day x Total Number of Animals x 365 Days

Organic Refuse Energy Year = Organic Refuse/Day x 2200Btu/lb x 365 Days

Total Energy Produced/Year = Animal Waste Energy/Year + Organic Refuse Energy/Year

Economics

To determine the cost of an anaerobic digestion system is a difficult task. Few anaerobic digestion systems are

To further assist you in the assessment of your costs, the following guide to compute your payback period is presented.

Step 1. Calculate Money Saved per Year by Biogas Production

1. Obtain current price for fuels which you now use and which will be replaced by the biogas produced.
2. Convert price cited by utilities to price per million Btus of energy. (See Table 17.)
3. Using the total energy per year as calculated in the Energy Supply section, compute the money saved per year by substitution of current fuel for biogas.
   Savings/Year = Price/Million Btus of Current Fuel x Total Energy Produced/Year x 10^{-6}.

Step 2. Calculate annual waste treatment savings

1. Obtain cost of present means of sewage treatment ($/person/year).

Table 17. Table for Converting Price Cited by Utilities to Price per Million Btus

Natural Gas: Price/thousand cu. ft. x 1000 = price/million Btu
Fuel Oil: Price/gallon x 9.1 = price/million Btu
Electricity: Price/kWh x 2.93 = price/million Btu

Fuel	*Price Cited*	*Price/million Btu*

Table 16. Typical Daily Waste Produced per Day for Various Animals (Source: References (54) and (65))

Waste Type	Volume of Biogas/Animal (cf/d)	Energy Production Btu/d	Net Energy per Animal /year (million Btu)
Sewage	1.0	600	0.18
Hog manure	8.4	5040	1.49
Cattle manure	8.0	4800	1.42
Poultry manure	0.5	300	0.09
Organic refuse		2200 Btu/lb*	

* Organic refuse assumed to have 4000 Btu/lb; with a conversion efficiency of 55%, the usable energy production would be 2200 Btu/lb.

mass produced and this makes information on costs hard to obtain. Unlike large digester systems, which are primarily used for sewage treatment, smaller scale digestion systems are not widely utilized and as a result, there is a paucity of information on the costs and performance of these systems.

The economic viability of anaerobic digestion is largely dependent upon two factors. The first is the amount of energy the system produces and the cost of the energy it displaces. The second is the savings accrued by taking into account that anaerobic digestion is a means of waste management.

An economic analysis done by Kraft *et al.*(66) demonstrates that anaerobic digestion is a cost effective form of waste treatment. Of the four waste management practices assessed, anaerobic digestion employing a lagoon for waste storage proved to be more economical than an anaerobic lagoon, in-barn storage or an oxidation ditch and lagoon. The costing for the study was done for a digester which is designed to handle waste from a 500 head commercial hog operation (1,200-1,500 hogs/year). The scale of this digester is comparable in size with a system which can employ the sewage from about 2,100 people.

The major investment involved in an anaerobic digestion system is the air-tight tank. Therefore, the cost of the total system is primarily determined by the required size of the digester tank. The importance of the volume of the digester to its cost is shown in Figure 2, which reveals that the unit cost of the tan decreases as digester volume increases.

As might be expected, larger scale operations achieve economies of scale not possible with smaller operations. This is seen in Figure 3 where a nine-fold increase in people per year (1,700 to 15,300) reduced the net cost of the system from $3.30/person/year to $0.30/person/year.(66) The basis for these economies is found in the structure of the digester; namely that the volume of the digester increases at a greater rate than the surface area. Larger digester size means that lagoons can be smaller and hence their costs are lower. Also, as the digester increases in volume, the gas safety equipment, service building, and labor requirement remain virtually unchanged.

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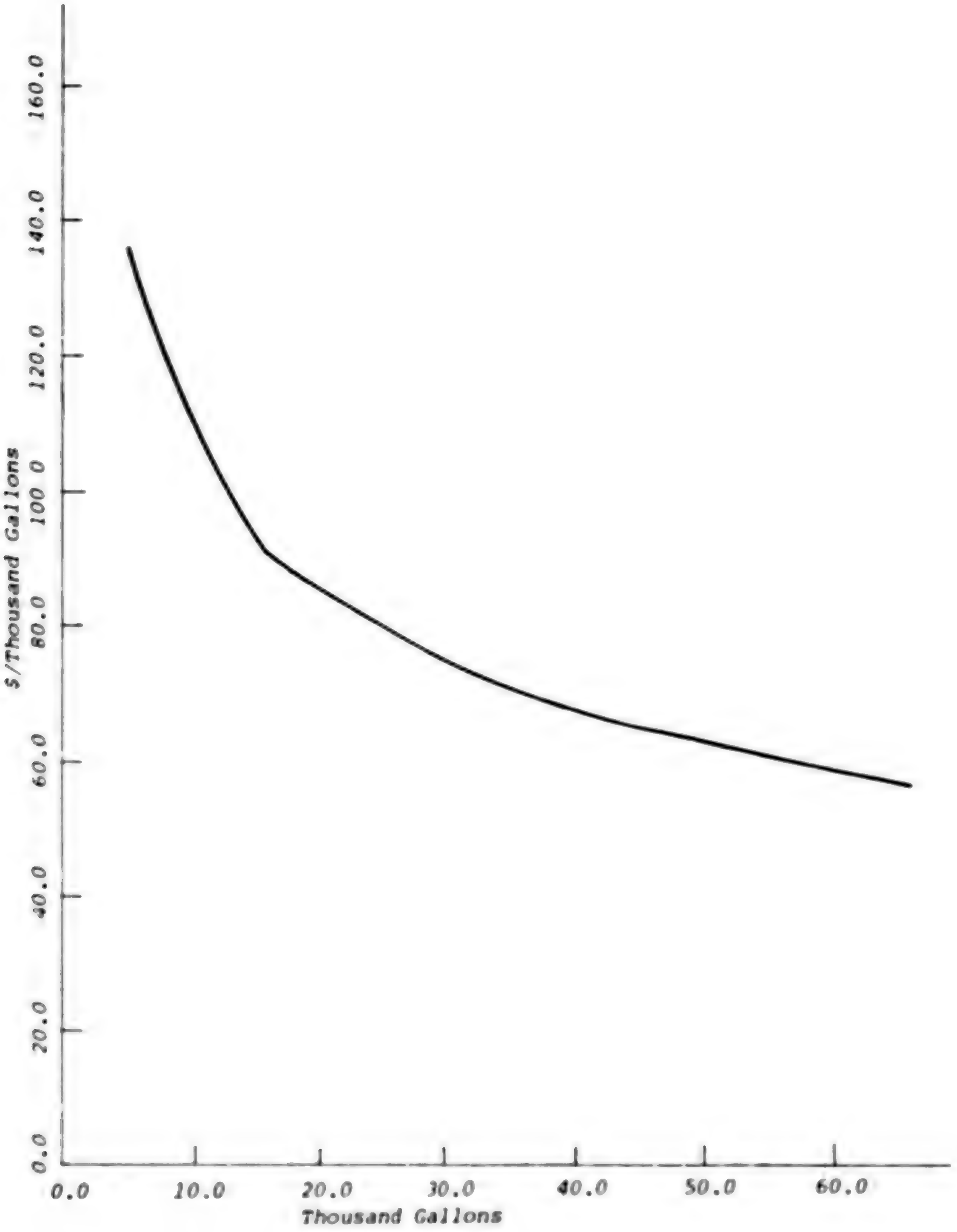

Figure 2. Average Cost of Digester Tank, Insulation Material and Mixing Equipment (Source: Reference (66)).

2. Using Figure 3, determine cost of your anaerobic digestion system ($/person/year).
3. Compute money saved per year from digestion as a waste management technique. Savings/Year = ($/person/year for current system - $/person/year for digestion system) x total number of people being serviced.

Step 3. Calculate Payback Period

1. Calculate total savings per year. Total savings/year = Savings of waste treatment/year + Value of biogas/year.
2. Using the cost of your system in $/person/year, compute total cost of your digester. Total Cost = $/person/year x total number of persons.
3. Compute payback period.

$$\text{SPP (years)} = \frac{\text{first cost (\$)}}{\text{first year savings (\$)}}$$

For additional information on the economic viability of various digester sizes and uses, see Table 18.

To conclude, it must be stressed that anaerobic digestion becomes more economical when it is considered as a form of waste management as well as a form of energy production. Today, the economic viability of digestion solely for energy production is poor. However, the work done by Kraft *et al* clearly demonstrates that anaerobic digestion is more cost effective than several means of waste treatment that you may now be employing. Therefore, it is essential that you include the waste management capability of anaerobic digestion in any economic analysis that you perform before making a judgment on the desirability of the technology.

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Table 18. Summary of Economic Analyses of Anaerobic Digestion Systems for Farm Animal Manure (Source: Reference (66))

	Location	Size of Operation	Method of Expression of Economic Feasibility
Swine	Ohio	10,000	Breakeven
	Ontario	3,000-10,000	$\$10.2-3.4/10^6$ Btu*
	Ohio	24,000	Breakeven at $2.0/mm Btu
Dairy	New York	100	$0.035/kWh
	New York	100	$\$10-25/10^6$ Btu*
	Vermont	200	$0.171-0.046/kWh*
	Ohio	2,700	Breakeven at $2.0/mm Btu
Beef	Upper Midwest	1,000	$1.25/gal gasoline (U.S.)*
	Kansas	35,000	\$0.63/MCF CH_4* ** ***
	Kansas	35,000	net energy loss
	Missouri	100,000	23% return on investment
Poultry	Maine	50,000 layers	$0.46/gal fuel oil (U.S.)*
	Connecticut	20,000 layers	$0.94/kWh*
	Connecticut	41,000 layers	$0.073/kWh*
	Connecticut	80,000 layers	$0.062/kWh*

*Cost of producing an equivalent amount of energy through anaerobic digestion.

**On a slotted floor, $2.65/MCF on a paved feedlot.

***MCF - million cubic feet.

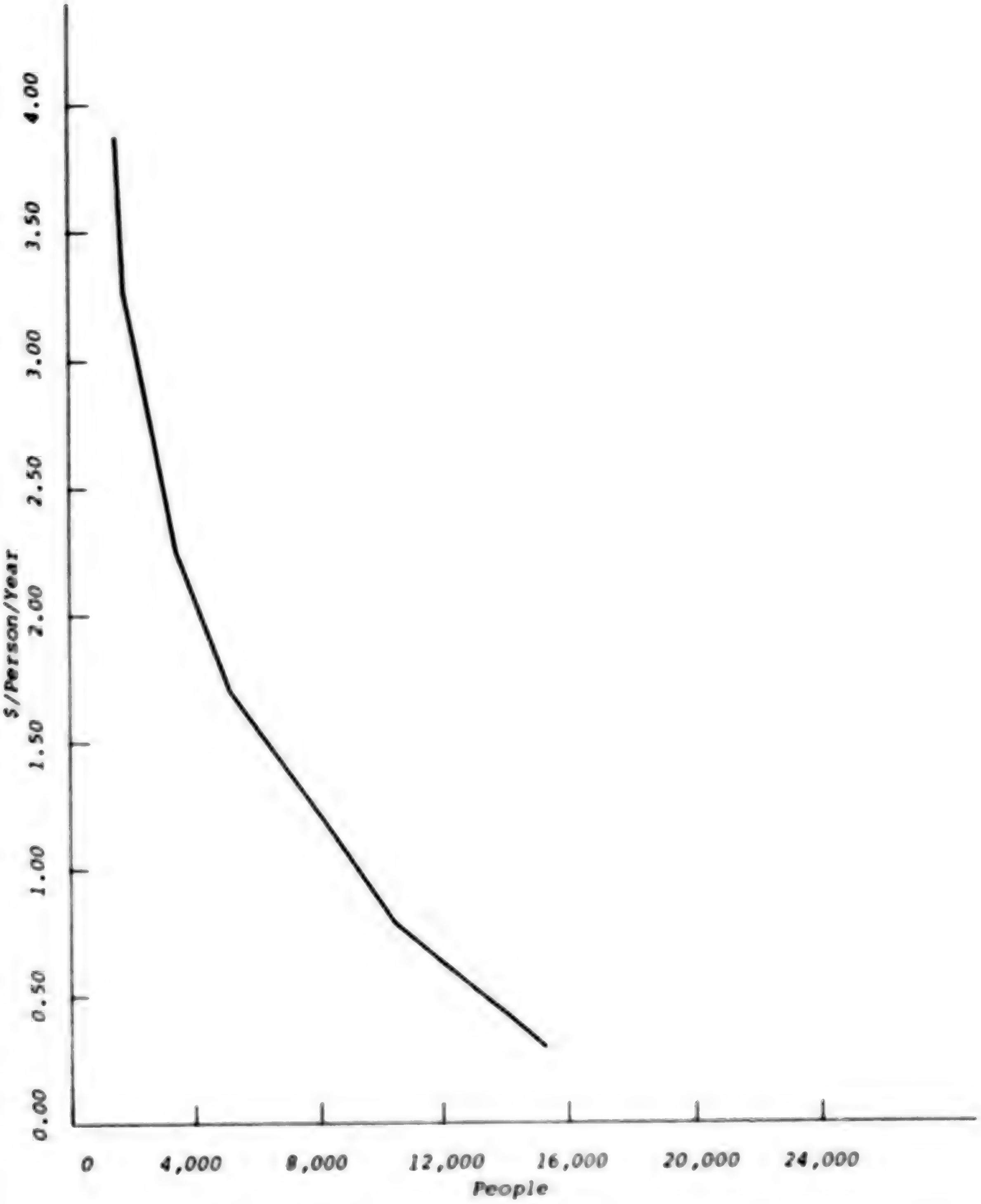
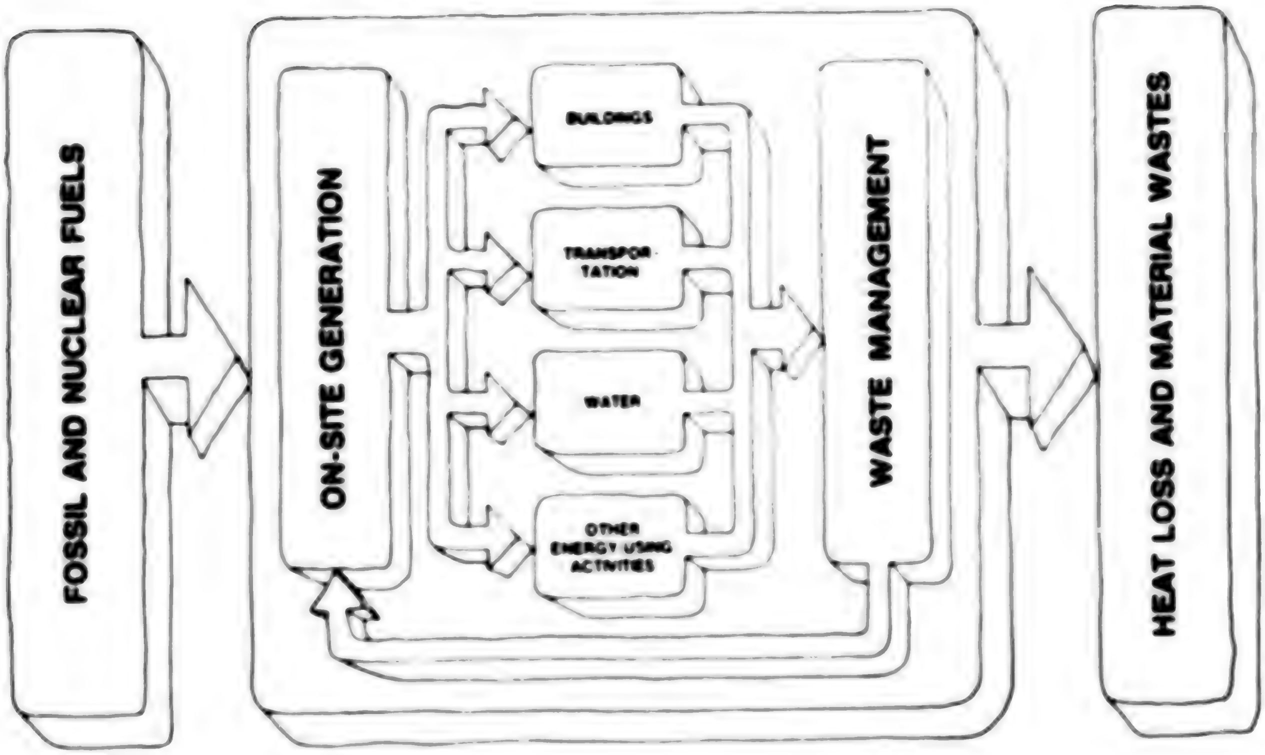


Fig 3. Annual Net Cost of Waste Treatment with An Anaerobic Digester (1978) (Source: Reference (66))

Biomass

SITE ENERGY-USING FUNCTIONS



COMBUSTION

BIOMASS

INTRODUCTION

Combustion is the burning of a substance, whether it be gaseous, liquid or solid. It involves the conversion of organic matter to heat and often light by oxidation. Decomposition, such as rotting, is a natural process of oxidation in which large complex molecules are broken down to simpler molecules such as carbon dioxide and water. During combustion, the decomposition process is speeded up and the energy given off in the breaking of the chemical bonds can be tapped for use.

The history of energy use by humans has been a history of combustion with little change other than the fuel. Traditionally, wood and dung were the fuels burned, as is still the case today throughout developing countries of the world. In industrial societies, these fuels have been replaced by oil and natural gas but oil and gas are being used more rapidly that they are created. As a result of this depletion of fossil fuel reserves, energy prices have escalated, encouraging examination of alternate energy sources such as solar, wind, and bioconversion.

Although any type of organic matter with a low enough moisture content is potentially suitable for combustion solid waste or refuse and wood or wood waste are likely to be the most suitable feedstocks within parks, refuges or hatcheries. Generally, these feedstocks are reasonably dry and are likely to be available. Since these two feedstocks present somewhat different problems and opportunities, each will be discussed separately.

SOLID WASTE COMBUSTION

Solid waste consists of materials which are either unusable or unwanted and which are subsequently disposed of by municipal services. Much of the solar and chemical energy that went into the production of the plants, animal material, and manufactured goods still remains in the solid waste when it is deemed no longer valuable. If this energy and materials can be reclaimed, it represents a significant increase in the efficiency of our overall energy and material use.

History

Historically, solid waste was disposed of in the same manner as were other wastes: by throwing it out the window into the street. As can well be imagined, in addition to presenting aesthetic problems, this form of waste disposal also presented severe health problems (e.g., the spread of such diseases as cholera, typhus, and plague). In response to this situation, the British Parliament in 1870 introduced the first legislation involving solid waste management under the first Public Health Act. One of the foremost intentions of this act was to control garbage disposal. The act specified that refuse must be placed in a container and made provisions for these containers to be cleared and for the waste to be collected and removed.

Since then, solid waste has generally been dealt with in the simplest and most economic fashion. Usually this meant dumping the waste at the city limits and possibly burning it to reduce the volume and/or the odors. In recent years, the amount of waste generated has been growing at a faster rate than the population, "garbage is the **effluence** of affluence." (68) This has imposed greater costs for land. In addition, land dumping generates considerable air and water pollution.

Technology and Fuel Source

Coupling these concerns with energy and material shortages has lead to the need to examine other forms of waste disposal, of which there are four main types: incineration, simple pyrolysis, partial oxidation, and reduction. Incineration is the direct burning of the refuse. Simple pyrolysis was discussed previously; it is the burning of the refuse in an air free environment. Partial oxidation has also been discussed (See sections on gasification and pyrolysis): the process is the burning of a substance in a limited oxygen environment. In reduction, the solid waste is reacted with carbon monoxide or hydrogen.

Incineration as a method of waste disposal began about 100 years ago in 1874 when attempts were made to burn municipal refuse in England. Those attempts failed because of the large quantity of wet garbage, the low temperatures attained, and the heavy production of odors (odors can only be eliminated if the temperature exceeds 1,200 degrees F). The first incinerator recorded in the U.S. was built on Governor's Island, New York Harbor, in 1885. (69) Since then, the composition of solid waste has changed; today, it contains more combustible materials such as paper. (70) Consequently, thermal processing is more feasible now and incineration is the most widespread type of thermal processing. Basically, incineration involves the burning of a substance in a furnace. Excess air is introduced into the furnace to encourage complete combustion. In spite of this, many unwanted by-products are produced, including aldehydes, hydrocarbons, and particulates. In order to meet air pollution codes, incinerators must have pollution control equipment to minimize the emission of these unwanted by-products into the atmosphere. All of this equipment is expensive, particularly the electrostatic precipitators which are the most effective.

Heat recovering incinerators are basically the same as other incinerators except they are composed of "water-walls." The furnace walls are made of metal with tubes through them, much like a flat-plate solar collector, through which water is circulated and heated by the furnace (usually to the boiling point). The steam produced is then used for space heating, electricity generation, or in industrial processes. Table 19 presents some of the characteristics of heat recovering incinerators. For a successful incineration system, it is necessary that the following provisions be included for carrying out certain essential functions: (71)

1. Receiving loads of mixed refuse at varying rates of supply,
2. Measuring the quantity of refuse received,
3. Storing in a sanitary, accessible, nuisance-free manner,
4. Sorting, mixing, or otherwise preparing refuse for incineration,
5. Feeding the refuse to the system at a controlled rate,
6. Drying the refuse sufficiently to permit ignition of combustibles,
7. Burning the refuse to produce essentially inert solid residue and clean gases,
8. Dissipating the heat of combustion,
9. Cooling, collecting, and removing noncombustibles,
10. Cleaning and discharging effluent gases and liquids in an acceptable form,
11. Controlling the process for safety, efficiency, economy, and community acceptance, and
12. Protecting personnel and equipment from the elements, dangerous refuse, and careless operation.

Advantages and Disadvantages

The advantages of combustion processes with solid waste are these:

1. With proper operation, health problems associated with refuse accumulation can be eliminated. The end products of effective incineration are CO_2, H_2O, N_2, and O_2.
2. Incineration can reduce the waste volume by about 60%.

Table 19. Characteristics of a Heat Recovering Incinerator.

1. *Moderate excess air.*
2. *Moderate size combustion chamber, but requires water tube wall construction, and may require additional parallel lines for steam supply reliability.*
3. *Furnace auxiliary equipment similar to refractory incinerators, but less costly due to lower gas flow.*
4. *Requires expensive steam facilities and controls, including water tube walls, waste heat boiler, boiler feedwater treating, soot blowers, steam condensers, and steam distribution.*
5. *Waste heat boiler producing steam used for cooling.*
6. *Operations complicated by necessity to meet steam supply demands, maintenance of steam equipment, presence of high pressure steam systems, etc.*
7. *Possible steam tube corrosion and erosion require monitoring and additional maintenance cost; air pollution control equipment corrosion can be problem as with refractory incinerators.*
8. *Higher operating costs because of increased complexity.*
9. *Considerable steam credits possible in addition to salvage, including in-plant use of steam for fan drives, heating, etc.*

3. Incineration is applicable at a wide range of scales.
4. Mixed garbage and rubbish are suitable feedstocks for the incinerator.
5. Incineration is a high intensity use of land; it reduces the amount of land required for disposal.

Disadvantages are these:

1. Landfill is still required.
2. Incineration is rarely effective and therefore, pollution control equipment is required, particularly to reduce particulate emissions and H2S produced when plastics are burned. This pollution control equipment is typically very expensive.

Assessing Suitability of Direct Combustion of Solid Waste

In order to make a preliminary assessment of the suitability of combustion of solid waste at your site, it is essential that you do the following three things.

1. Ascertain the demand for steam at your site. The decision to go to energy recovery from solid waste is governed primarily by the nature of the market for steam, including demand patterns and potential value.
2. Determine how much of your energy demand can be met by steam. The amount of steam

which can be produced is largely dependent upon the amount of solid waste available and its composition.

3. Determine the economic viability of an energy recovering system at your site. This will depend on the facilities' capital and operating costs, the amount of steam produced and the potential market for it plus the amount of savings accrued over other forms of waste disposal.

Energy Demand for Steam

Having a potential user for the steam produced is essential before deciding to produce steam. Generally, there are three main uses of steam: heating, generating electricity, and industrial processes.

Energy Supply of Steam

Now that you have determined the appropriate uses for the steam, it is time to find out how much energy you can produce. This will largely depend upon the total amount of solid waste available and its composition. The composition is important since the energy content of solid waste varies greatly depending on the relative amounts of moisture, and combustible and non-combustible materials as shown in Table 20.

There are two factors which affect the availability of solid waste: the total amount generated and the ease with which it can be collected. This is a function of the concentration of the feedstock and the seasonal distribution of its production.

First, determine the potential energy available. If the total mass and composition of the waste is known, Table 21 can be completed to determine the total energy potentially available.

If this information is not known, it can be estimated from national figures. Typically, 70 to 80% of municipal waste is combustible. (73) A median figure of 5,000 Btu per pound can be assumed. If the total mass, but

Table 20. Energy Content of Solid Waste as a Function of Composition (Source: Reference (72))

Nominal Refuse Heating Value; Btu/lb	*6500*	*6000*	*5000*	*4000*	*3000*
Refuse, % Moisture	*15*	*18*	*25*	*32*	*39*
% Noncombustible	*14*	*16*	*20*	*24*	*28*
% Combustible	*71*	*66*	*55*	*44*	*33*
TOTAL	*100*	*100*	*100*	*100*	*100*
Steam Generated; tons/ton refuse	*4.3*	*3.9*	*3.2*	*2.3*	*1.5*

Table 21. Determine Total Energy Potentially Recoverable (Source: Reference (70))

	Mass of Component per Year	*Btu Content*	*Total Btus*
Paper products		*7660*	
Wood		*7825*	
Brush, branches		*7140*	
Leaves		*4900*	
Grass		*3820*	
Garbage		*1820*	
Greenstuff		*3470*	
Greens		*4070*	
Rags, cotton, linen		*6440*	
Rubber		*12,420*	
Plastic		*16,000*	

not the composition, of the solid waste is known, this figure can be used as an estimate. If the total mass is not known, then the total amount of solid waste can be estimated from the number of people who are generating it. Waste production per person per day varies from about 0.8 pounds to 3.3 pounds depending on the income, size of city, and many other factors. The median value, about two pounds of solid waste generated per capita per day, is probably as good an estimate as any other. If the weight and composition of the solid waste generated each year is known, the total energy available is simply determined by filling in Table 21 and adding up the right column.

If the mass generated per year is known, the total energy potentially recoverable can be estimated by using the following equation:

TEPR = MSWG x 10 x 106 Btu/ton

where TEPR is the total energy potentially recoverable per year, and MSWG is the mass of solid waste generated per year.

If the total mass of solid waste produced is not known, the total energy potentially recoverable can be estimated by using the following equation:

TEPR = population x 2 lbs/day x 365 days/year x 5,000 Btu/lb.

Since no process is 100% efficient, incineration included, it is necessary to multiply the total energy potentially available per year by the efficiency of the process to determine the actual energy which might be recovered. Although the efficiency of the process depends on the specific equipment, the composition of the waste, and the type of operation, 60% is an average energy efficiency. Therefore,

RE = TEPR x 0.6

where RE = the recoverable energy per year, and TEPR = the potential energy recoverable per year (calculated above).

7. Economics

Determining the economics of an energy recovering incinerator is a difficult task. The problem of scale is significant. The only incinerators that are presently used to recover energy from solid waste are either prototype units in the order of 10 to 35 tons per day (that is, to serve 10,000 to 35,000 people per day) or very large units in the order of 1,000 tons per day or more (designed to serve a million people or more).

Such large scale incinerators are probably not suitable for parks, refuges, or hatcheries since the population is not large enough to support such an operation. Although a 10 to 35 ton per day unit might be appropriate in some cases, in most cases even this size facility is probably too large. In either case, these prototype facilities will not be cost-effective.

There may however be a cost-effective means of reducing waste and saving energy. This is source separation and recycling. (See also Volume I, *Reference Manual*, Waste Management.) Marblehead instituted such a program and found it to be highly cost-effective as is clear from Table 22. (74) Table 23 shows the order of energy savings which can reasonably be expected to be attained by recycling.

Such a program depends upon a co-operative community. Prior to introducing their program, Marblehead had a six month education period to inform citizens of the program. Although this could probably be accomplished fairly simply for residents of parks, it is possible that park visitors may be less cooperative.

The program also depends on having a client for the materials to be recycled and potential clients should be found before any such program is instituted.

WOOD COMBUSTION

Wood is a versatile resource. It has long been recognized as useful from aesthetic, environmental, and material perspectives. In the future, it is likely that it will be recognized as an important source of energy.

A tree is a biological solar collector which captures and stores sunlight by photosynthesis, the process that converts atmospheric carbon dioxide into cellulose and other complex organic molecules which make up wood. Because wood contains solar energy stored as chemical energy, wood is a valuable source of renewable energy.

History

For centuries, heating needs were met entirely by the heat produced from the combustion of wood. Early fireplaces were large, dirty, and inefficient until significant design improvements were made in the 17th and 18th centuries. In the U.S., Benjamin Franklin was one of the major contributors to the improvements made in combustion technology. His Franklin fireplace was a great improvement in energy efficiency over the conventional fireplace.

In the U.S. between 1850 and 1900, the wood-burning cast-iron stove was the major source of heat for hot water heating and cooking. When fossil fuels became readily available, wood was replaced first by coal used in coal-burners and then later by oil and natural gas.

The fireplace has always remained popular primarily for aesthetic reasons. However, its prominence as a source of heat is coming to the fore again, as is the importance of wood stoves and furnaces, due to the increasing shortages and rising costs of fossil fuels.

Wood heating technologies have greatly improved since the beginning of the 20th century. Advances in design have improved the energy efficiency of fireplaces, stoves, and furnaces and have also made the combustion of wood a much safer and cleaner technology for producing usable heat. Today, the burning of wood is an attractive alternative to fossil fuels as a source of heat.

The combustion of wood has many uses. Wood can be burned to produce

Table 22. Marblehead Program Economics

Month 1977	Revenues from sales	Diverted disposal savings	Incremental collection costs *	Net savings
January (12-31)	$1,870	$2,990	$2,930	$1,930
February	2,560	3,390	3,570	2,380
March	3,790	3,680	4,450	3,020
April	3,500	3,640	4,470	2,670
May	3,400	3,390	3,850	2,940
June	3,730	3,850	4,240	3,340
July	3,280	3,350	4,040	2,590
August	4,340	3,850	4,250	3,950
September	3,360	3,580	4,050	2,890

* Includes Labor costs as well as operation, maintenance, and capital amortization for the compartmentalized trucks and all other equipment added as a result of the source separation program.

Table 23. Production Energy Potentially Saved by Recycling

		Energy Cost (106Btu/ton)		
Material	Point of Impact	Virgin Material	Recycled Material	Percent Saved
Steel	Molten Steel	46.7	22.6	52
Aluminum	Molten Aluminum	224.5	8.2	96
Plastics	Molten polymer	45.2	2.0	96
Paperboard	Pulp	6.6	3.3	50
Glass	Transportation	7.8	7.8	0
Copper		50.0	3.0	94

heat for cooking, water heating, and space heating. It can also be used to generate electricity or to produce heat and electricity by cogeneration. This section will concentrate on combustion technologies associated with the production of heat from wood.

Technology and Fuel Source

There are two basic types of wood-burning heaters. Open heaters such as stone and metal fireplaces have open hearths and thus allow little control over the combustion process. Enclosed heaters, such as stoves and furnaces, are air-tight and have higher energy efficiencies. (See Table 24.)

Masonry fireplaces have an average heating efficiency of less than 10%. On very cold days when the temperature difference between the indoor and the outside air is about 20° F, the efficiency can drop as low as 0%. In fact, the masonry fireplace can become a heat drain. The damper must remain open as the fire burns down and this results in warm air being sucked from the room up the chimney.

The efficiency of the conventional masonry fireplace can be improved in many ways. One simple way is to install tightly fitting glass or metal doors which will prevent the warm air in the room from escaping up the chimney. Another method is to place a small draft vent over the fireplace when the fire starts to burn down. The installation of a "thermograte" can also increase the energy efficiency of the fireplace. A "thermograte" is a grate composed of U-shaped tubes that draw cool air at the bottom and force hot air into the room from the top. A coil [illegible] piping installed in the firebox [illegible] way up the chimney is the most effective means of increasing the energy efficiency of the fireplace, but it is also the most costly.

Metal fireplaces are more energy efficient than conventional masonry fireplaces. The metal fireplace consists of a large metal hood over a base that hold the fire. When it is placed in the center of the room, the metal fireplace provides a more uniform heat distribution. Prefabricated metal fireplaces are available, but they may be less energy efficient than the non-prefabricated units. Prefabricated units are typically covered with a masonry veneer which is a less effective radiator than an exposed metal surface.

The Franklin fireplace is a compromise between the aesthetics of an open hearth and the efficiency of a closed stove. It has closable doors which allow higher firebox temperatures and some draft control. Another feature of this fireplace is that it can be installed in front of an existing fireplace and connected to the existing flue.

Airtight stoves have higher energy efficiencies than any of the fireplaces or the Franklin fireplace. The higher efficiencies are achieved by providing air in the correct amounts as needed. Also, the modern wood stove routinely maintains a fire for more than 12 hours, and the ashes need to be removed from the stove only once a week.

A wood burning furnace is the most efficient wood heater available. Like an oil furnace, it takes up a lot of space and is very similar to a large circulator-type stove. It has a firebox so that wood and most residue is reduced to a minimum amount of ash. The best models feature an intake damper controlled by an automatic thermostat. The damper closes automatically if the stove overheats, and opens to allow more air to enter if the fire gets too low. The furnace can hold a fire from 12 to more than 24 hours before more wood must be added.

To distribute the heat from the furnace, air is drawn around the firebox and circulated through ducts in the building. Some furnaces can be used with hot water distribution systems and, in this case, the firebox is surrounded by water which is then piped into baseboard radiators or radiant floor systems.

Wood combustion is almost never complete. Smoke and ash are the two

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Table 24. Comparison of Wood Heaters

	Masonry Fireplace	Masonry Fireplace with Heat-Circulating Unit	Metal Fireplace	Franklin Stove	Closed Stove	Combustion Burner
Relative cost -labor ($ or time)	very high	very high	low	low	low	low
-materials	variable	medium to high	low to medium	low	low to medium	medium to high
Comfort & Convenience	fair	fair	fair	fair	fair	good to excellent
Heating Efficiency	poor to fair	fair to good	good	good	very good	excellent

major by-products of wood combustion.

Wood smoke almost always contains unburned gases and tar-like liquids. Some of these will condense out of the flue gases onto a relatively cool surface. This condensate is called creosote and is usually brown or black. It has an unpleasant acrid odor. Carbon particles and ash are also contained in the smoke. The carbon particles are referred to as soot when they are deposited on surfaces such as the fireplace, stove, or chimney walls.

The solid residue in the wood heater is ash. It is a valuable fertilizer mainly because of its high potassium content. Potassium carbonate can be extracted from the ash and is used in making soap. Wet ash is caustic and can be utilized as a degreasing cleanser.

The air pollution created by wood combustion is different from the pollution produced by fossil fuels. Like the combustion of fossil fuels, the combustion of wood uses oxygen and adds heat and carbon dioxide to the atmosphere (75). However, the emissions of sulphur oxides and nitrogen oxides from wood combustion are considerably lower than those generated by the burning of fossil fuels.

The emissions of particles and unburned compounds, however, are higher for wood than for most fossil fuels. The costs of pollution control can be borne by the producer for industrial-size burners. However, for most domestic wood heaters, the costs of pollution control devices are prohibitive. Therefore, these burners usually emit a considerable amount of smoke. A large number of chemicals are found in wood smoke, but very little is known about their effects. Therefore, further research is needed to determine the nature of the impacts of the chemicals present in wood smoke.

Several factors should be considered when choosing wood for fuel. The energy content of the wood is one important criterion. Other qualities such as easy ignition, rapid burning, freedom from smoke, and uniform heat are also worthy of note. Generally, softwoods burn more easily than hardwoods and are used for kindling.

Another important feature is the ease with which wood can be split. This is particularly relevant if you are chopping your own wood. Types of wood which have a straight grain and are free of knots are much easier to split than those with a twisted grain. The easiest woods to split are usually conifers. Some of the most difficult woods to split are elm, sycamore, dogwood, and red gum.

Most softwoods produce a lot of sparks and this can be a severe fire hazard unless the wood is densified*. Although drying can reduce sparking, some resinous softwoods such as spruce and hemlock should be used with caution in an open fireplace.

Some types of wood burn more cleanly than others. Wood with a high moisture or resin content can produce a smoky fire. Excessive smoke can be hazardous, particularly if large deposits of soot and creosote accumulate in the flue. These deposits are very flammable and can cause a sudden chimney fire. Most softwoods produce a lot of smoke and any type of green wood can cause a smoke problem unless used sparingly in a hot fire.

Green wood is always heavier, harder to handle and ignite, and contains less energy per unit mass than seasoned wood. When burned, some of the energy produced by the wood is used to evaporate the moisture in the wood and therefore, less usable energy is available.

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*A process in which the wood is subjected to high pressures to remove air pockets (and often moisture to some extent). Wood which has been so densified has been referred to as "bio-coal."

Burning green wood does have some advantages. Due to its high moisture content, green wood burns more slowly. If you are interested in obtaining a steady, low heat output over a long period of time, overnight, for instance, mixing some green wood with some dry wood is ideal. Knowing the appropriate proportion and size distribution of green wood required comes from experience. If too much green wood is added, the fire will die out.

The proper storage of fuelwood is necessary to keep the wood in the best condition for burning. Since green wood contains a large amount of moisture, it should be stored to allow it to dry. After a month of drying, the wood is seasoned and usually has a moisture content of 25%. The moisture content of wood never reaches zero% under normal conditions. Rather, the moisture content approaches an equilibrium depending on the storage conditions.

If several conditions are met, the storage time of the wood can be reduced. If the wood is cut and stored in small pieces it will dry more quickly. The better the air circulation around each log, the faster will be the drying process. Also, direct exposure to sunlight as well as indoor storage will accelerate the drying process.

If stored for a long period of time, the fuel value of the wood may deteriorate due to rotting. Rotting is caused by the growth of fungi. Like fire, the fungi convert wood into water, carbon dioxide, and heat, and thus, rotting decreases the energy content of the wood. The fungi are most productive at temperatures between 60°F and 90°F, at a moisture content of greater than 30%, and in an environment with an ample oxygen supply. (76)

Safety is a major consideration in the installation and operation of all wood heaters. There is little doubt that fires are more likely to occur in buildings with wood heating systems than in buildings with conventional heating systems. Most fires associated with wood heating are due to unsafe installations rather than to any inherent danger of using wood as a fuel. By complying with safety standards and building codes, virtually all danger can be eliminated, except for the carelessness of the operator. (77)

Advantages and Disadvantages

The advantages of wood combustion are these:

1. Wood is a renewable source of energy.
2. Technologies for wood combustion are well-known and proven.
3. Wood heaters are relatively inexpensive and easy to operate.
4. Emissions of SO_x and NO_x are very low.
5. The ash by-product is a valuable fertilizer.

Disadvantages are:

1. Wood heater systems are more labor-intensive than conventional heating systems.
2. Storage space is required for the fuelwood.
3. Emissions of particulate matter are high.
4. Wood heaters can be a safety hazard if improperly installed or carelessly operated.

Assessing Suitability of Wood Combustion

In order to make a preliminary assessment of the suitability of wood combustion at your site, it is essential that you do the following three things.

1. Ascertain the demand for energy from wood at your site. There is no point in having a fuel which cannot be utilized.
2. Determine how much of your energy demand can be met from the combustion of wood. The amount of energy which can be produced is largely dependent upon the amount of wood available and the type of conversion technology used.
3. Determine the economic viability of wood combustion at your site. This will depend upon the capital and

operating costs of the conversion technology and the cost of the fuel which the wood is displacing.

Energy Demand for Wood

Before deciding to produce energy from wood combustion, you must first find out if the energy produced can be put to good use. An inventory of your current energy uses and the type of fuel being employed for each use will help you to assess which uses can be fueled by wood. An examination of your current natural gas and/or propane bills will give you a good idea of the total amount of fossil fuel energy which can be replaced by wood energy. This is useful, particularly, if you cannot determine how much energy is being supplied by each type of fuel for each end-use. (See Table 25).

Table 25. Wood Demand Chart

Energy Use	*Present Fuel*	*Rate of Energy Use of Present Fuel*	*Rate of Use of Wood*
Space Heating			
Water Heating			
Etc.			

Energy Supply of Wood

Now that you have determined the appropriate uses for the wood, it is time to find out how much energy you can produce. This will largely depend upon the total amount of wood available for combustion.

The availability of the wood is primarily due to two factors. Many parks and refuges have an extensive forest cover, a potential source of wood or wood waste. However, the proximity of the woodlots to the buildings which house the fireplaces, stoves, or furnaces as well as the ease with which the wood can be collected and transported will determine how much wood can actually be tapped economically.

Another important factor which influences the availability of wood for combustion is the amount of wood which can be taken from nearby woodlots with a minimum of environmental impact. This is a management question. Clear-cutting of large areas leads to erosion, loss of habitat and changes in microclimate and the removal of large amounts of wood residues hinders soil rejuvenation since valuable nutrients are lost. Therefore, when deciding how much wood you can cut or gather, you must apply wise management techniques to ensure that a sustained yield of wood is maintained and that negative environmental effects are minimized.

Table 26. *Approximate Weight, Available Heat of Different Woods*

(Source: Reference (78))

Type	Weight		Available Heat per Cord *		Percent more Heat From Air-Dry %
	Green Weight (lbs)	Air-Dry Weight (lbs)	Green	Air-Dry	
Ash	3,840	3,440	16.5	20.0	21
Aspen	3,440	2,160	10.3	12.5	25
Beech, American	4,320	3,760	17.3	21.8	26
Birch, yellow	4,560	3,680	17.3	21.3	23
Douglas-fir, heartwood	3,200	2,400	13.0	18.0	38
Elm, American	4,320	2,900	14.3	17.2	20
Hickory, shagbark	5,040	4,240	20.7	24.6	19
Maple, red	4,000	3,200	15.0	18.6	24
Maple, sugar	4,480	3,680	18.4	21.3	16
Oak, red	5,120	3,680	17.9	21.3	19
Oak, white	5,040	3,920	19.2	22.7	18
Pine, eastern white	2,880	2,080	22.1	13.3	10
Pine, southern yellow	4,000	2,600	14.2	20.5	44

* *Standard cord-to-stack 4 ft x 4 ft x 8 ft containing 80 ft^3 of solid wood. Millions of Btus*

Once the availability of the wood is known, the next step is to calculate how much energy the wood can produce. Table 26 tells you the potential energy contained in various types of wood, and Table 27 indicates the conversion efficiencies for various combustion technologies. With this information, you can calculate the total amount of energy available from wood.

The following equation will enable you to calculate the total amount of energy available per year from wood. Total Available Energy=Energy/cord (Table 26) x Number of cords x Conversion efficiency (Table 27).

Economics

The economic viability of the combustion of wood is largely dependent upon two factors. The first is the total cost of the wood conversion technology. The second is the amount of energy the system produces and the cost of the fuel that the wood displaces.

To assist you in the assessment of your costs, the following guide to compute your payback period is presented. Step 1. Find out the capital cost of the wood conversion technology you have chosen. The best way to do this is to consult a local wood heater manufacturer or a retail outlet which sells the type of system you require. The wood technology industry is growing in the United States and there are many manufacturers as well as stores throughout the country which can give you the selling price of their equipment.

Table 27. Wood Heater Efficiencies
(Source: References (79) and (80))

Type	Efficiency
Masonry Fireplace	15 - 35% efficient for continuous use 0-14% most common
Metal Fireplace	good designs may achieve efficiencies close to those of metal stoves
Franklin Stoves	30 - 50%
Metal Stoves	40 - 80%
Furnaces	40 - 80%

Step 2. Calculate the money you save per year by using wood for fuel. Obtain current price for fuels which you now use and which will be replaced by wood. Convert price cited by utilities to price per million Btus of energy. Using the total energy available per year as calculated in the Energy Supply section, compute the money saved per year by substitution of current fuel for wood. (See Table 28).

Table 28. Table for converting price cited by utilities to price per million Btus.

Natural Gas: Price/thousand cu. ft. x 1,000 = price/million Btu
Fuel Oil: Price/gallon x 11.36 = price/million Btu
Electricity: Price/kwh x 2.93 = price/million Btu

Fuel	Price Cited	Price/million Btu

$$\text{Savings/year} = \frac{\text{Total Available Energy} \times \text{Price/million Btus of current fuel}}{1{,}000{,}000}$$

The analysis in Table 28 assumes that the operating costs of the wood combustion technology are negligible; that is, the costs of buying, cutting, transporting, and storing wood as well as the operation of the wood heater is assumed to be zero. If these costs are significant to you, then they must be subtracted form the total savings/year as in the following equation.

Net savings/year = Savings/year - Operating costs/year.

Step 3. Calculate your payback period.

Payback period = Capital cost of wood heater ÷ net savings/year.

In conclusion, it is apparent that wood heaters are one of the best energy alternatives available for parks, refuges, and hatcheries. This is particularly true where the energy costs are high and where there is extensive forest cover.

BEST DOCUMENT AVAILABLE

BIOMASS

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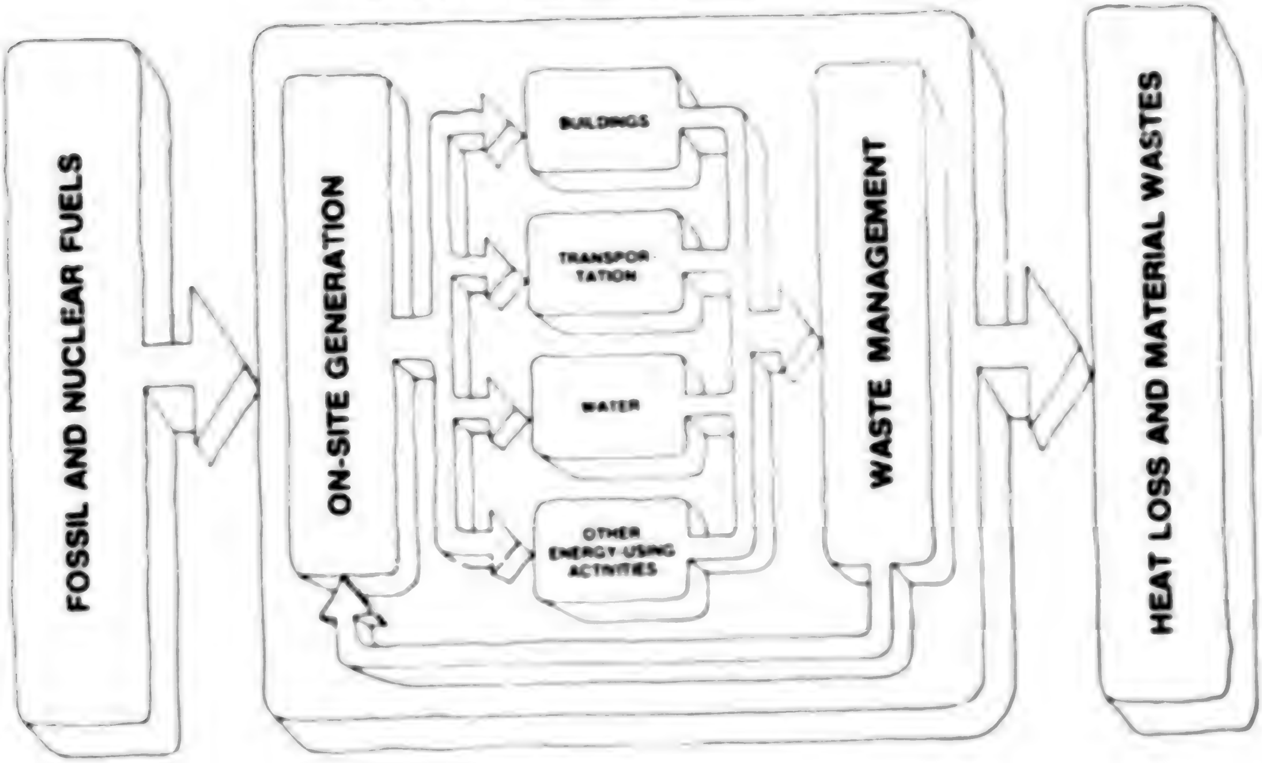
Cogeneration

SITE ENERGY-USING FUNCTIONS



PHOTOVOLTAICS

ECONOMICS

When it has been determined what size solar cell system is needed, Table 1 should be consulted for the costs of various size systems. Because the price for solar cells is rapidly decreasing, projected costs are listed as well. The U.S. Depart-

assumes easy and low-cost access to the utility grid. If there is a connect charge to obtain utility electricty, it must be figured into the cost.

For solar cell systems larger than one Watt, multiply the cost per Watt and savings per year figures by the Watt rating that your site needs.

Some solar cell manufacturers

COGENERATION

INTRODUCTION

Cogeneration, in the broadest sense, refers to any multiple use of a particular energy flow. In this inventory of on-site generation technologies, cogeneration is the combined production of electricity and process heat. "Generation" refers to the conversion of some fuel to a useful form of energy; "Co-" refers to the use of a single fuel for two purposes rather than one. The underlying principle behind cogeneration is the use of waste energy from one energy-consuming process to drive another. Thus, cogeneration is sometimes referred to as the sequential use of energy. Application of this principle can be found throughout natural systems and in earlier historical epochs. Because cogeneration involves getting extra use out of the same fuel, it can be viewed as a form of conservation.

Cogeneration is possible because different uses of energy require different types of fuel input. Burning fossil fuels separately for different uses is wasteful if the waste from one use or process is suitable to fuel another. For example, a university or large industry may use the waste heat from its own electric generation system to meet thermal requirements of its buildings. In principle, then, heating water over a wood stove is cogeneration, as is heating a car with waste heat from the engine. In natural systems, "cogeneration" might better be referred to as "multigeneration" because every flow of energy in the biosphere drives more than one process, and the waste from each process then drives another. Ultimately all energy flow ends up as low grade heat which warms the atmosphere and is then radiated out to space.

HISTORY

Large-scale cogeneration of electricity and process heat has long been technically and economically feasible. Cogenerators were used extensively in the early years of American industry, and accounted for about 22% of U.S. electric power supply in 1920. This percentage decreased to 18% in 1940 and to about 4% by 1976.(1) The decline in use of cogeneration was largely a result of decreased fuel and capital costs for electric power facilities used by utilities in the 1950s and 1960s, and the resulting low prices for bulk power sold to industry. Utility companies also discouraged industrial cogeneration by declining to buy surplus cogenerated power at a fair price while, at the same time, charging exceptionally high fees for backup power supplied to companies using cogeneration as a prime source. Some industries with considerable potential for cogeneration did not go into the power business because of its historically low return on investment -- they preferred to expand their primary market instead. These industries also preferred to avoid coming under the jurisdiction of utility regulatory agencies. For example, large paper companies were profitably cogenerating in the 1920s and 1930s, but were forced out of the business when the Justice Department required them to decide whether they were in the paper or the electrical power business. In Germany, because these problems either do not exist or are relatively minor, 30% of the electric power supply still comes from cogeneration facilities. The widespread use of cogeneration is one of the reasons why many European countries use only about one-half the energy per capita as in the U.S., even though they have a similar standard of living.

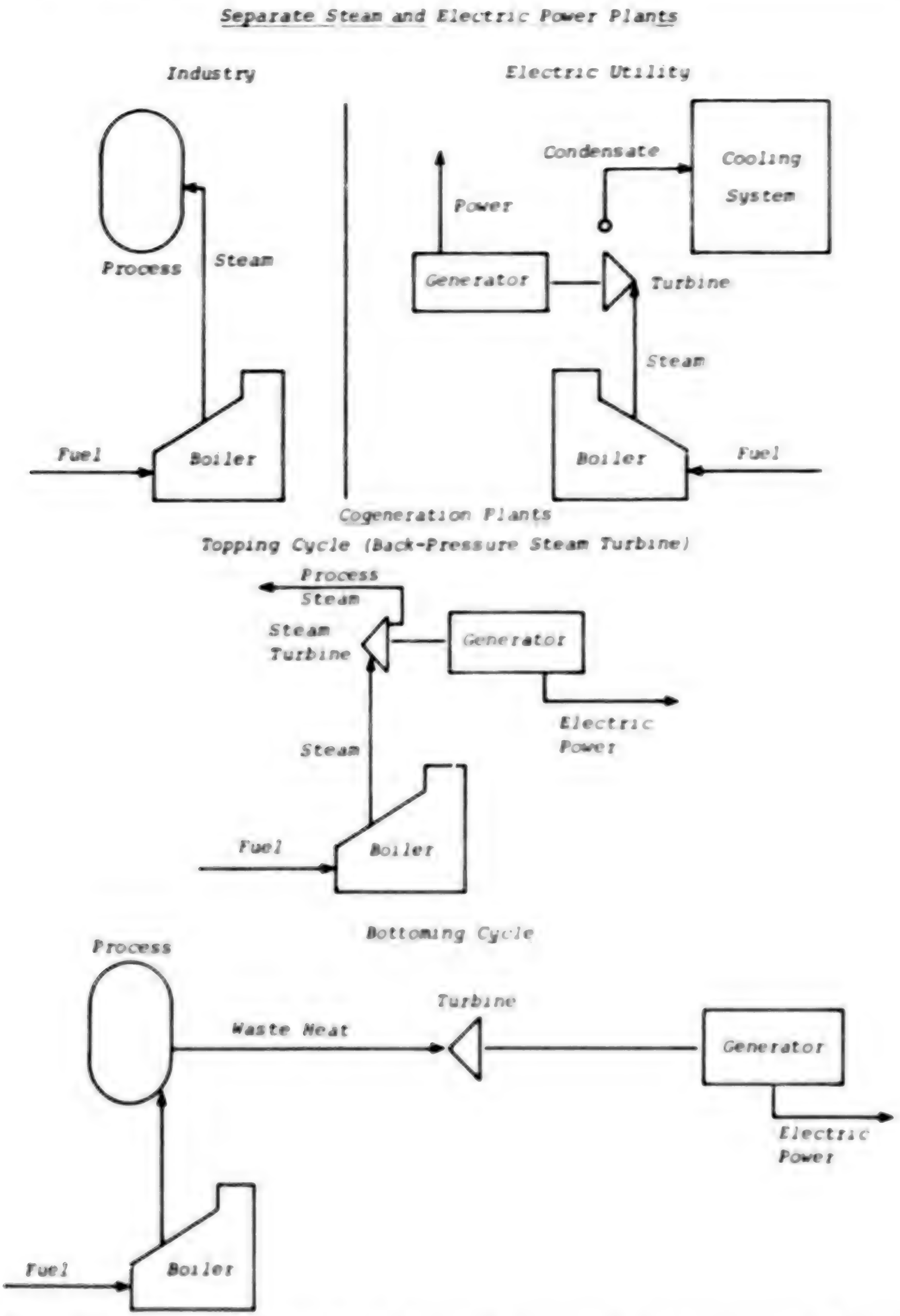
TECHNOLOGY

Cogeneration usually refers to the combined production of electricity and low or high grade heat. The two basic approaches to cogeneration are called "topping" and "bottoming" cycles. (See Figure 1.) The "topping" cycle is the most widely applicable form. It involves adding a generator to the front of a

PHOTOVOLTAICS

Table 2. Costs per Watt and Potential Savings

Cost per Watt	Utility Rate (¢/Watt hr.)	Savings per Year*	Payback Period	Utility Rate	Yearly Savings	Payback Period
$12.00	.02	$ 3.66	164 yr.	.04	$ 7.32	82 yr.
8.00	.02	3.66	109	.04	7.32	55
2.00	.02	3.66	27	.04	7.32	14
.50	.02	3.66	6.8	.04	7.32	3.4


Separate Steam and Electric Power Plants

Cogeneration Plants

Topping Cycle (Back-Pressure Steam Turbine)

Bottoming Cycle

Figure 1. Flow Diagrams for Simple Electric Generation and Cogeneration Systems

PHOTOVOLTAICS

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Disadvantages

Disadvantages of cogeneration systems include the need for a utility that will act as a working partner by purchasing surplus electricity. Without such an arrangement, installation of cogeneration systems may not be economically viable. A second disadvantage is that diesel-powered cogeneration units have some pollution emission problems.

APPLICATIONS AND REQUIRED ENVIRONMENTAL CONDITIONS

Cogeneration of heat and electricity span the scale of operation from 15 kw Fiat units to 500 kw units for hospitals, schools, or small industries to 70 Mega Watt units for a large industry. But because only larger scale units are now commercially available, only a few of the larger sites will find immediate use for cogeneration. It is anticipated that in the next few years, smaller scale units will be commercialized, making the technology practical for smaller applications. Though the principle of cogeneration is simple, selecting the exact system to meet your needs requires sophisticated and specialized engineering expertise. Therefore, the materials presented here can only be used to make a preliminary assessment and should be considered introductory. If you have a large site that uses large amounts of hot water or steam heat, you may well be able to use cogeneration. Make a preliminary assessment, then seek professional guidance.

The amount of electrical and thermal production is determined by site requirements and whether site management wants to indigenously meet all or a portion of its electrical and thermal needs in this way. For example, a site manager may want to meet all of the thermal demands and export surplus electricity, or he may opt to meet electrical demand and compensate for thermal energy needs through another source, such as wood. The former option -- exporting surplus electricity -- demands a hook-up to the electrical grid and an obliging utility.

PRODUCTION POTENTIAL

The technology of cogeneration differs in several important ways from the others presented as on-site sources of energy. First, the fuel sources are conventional fossil fuels -- diesel, gasoline, or even coal and natural gas. (In the future, many of the same fossil fueled processes may utilize renewable energy sources such as wood or methane to a greater extent.) Second, selecting cogeneration equipment to retrofit an existing system or to install as a new system requires going through sizing procedures for both electrical and heating outputs.

For the largest percentage of applications, the system will be sized to meet the heating requirements of the building, facility, or site. There is sufficient design flexibility so that the resulting electrical output of the chosen system can meet all, most, or very little of the site's electric demand. If the cogeneration unit is bought as a package from a manufacturer, there is less choice regarding the level of electrical output for a given thermal output. Most manufacturers will custom design a cogeneration unit to meet required specifications for any facility.

If the unit is chosen and sized primarily to meet the heating needs of a facility, there are three possibilities of electrical output.

1. Electricity production will exactly meet the demand at the site. In this case, an emergency back-up generator or a small battery storage system would be required to supply power at times of peak demand.
2. Electricity production will be lower than the level of demand. Electrical needs will have to be met by a supplemental system such as the utility grid.
3. Electricity production will exceed demand. Surplus electricity is sold to the local utility and

Storage and Grid Integration

process that produces lower grade heat. This requires first increasing fuel consumption to raise combustion temperatures high enough for electrical generation, then using waste heat from generation to yield lower grade steam, hot air, or water for heating. "Bottoming" cycles may be used with high temperature industrial processes that produce so much heat that the waste heat is of high enough quality to make steam, turn turbines, and produce electricity. In this case, the generator is added to the "bottom" or end of the industrial process. Basic production in both paper and steel industries is run at temperatures high enough to make this approach feasible.

Cogeneration is twice as efficient as conventional central power stations (60% compared to 30%). Although cogeneration plants operate on high grade fuels yielding temperatures of over 3,000 degrees F, "topping" engines reduce the inefficiencies which exist at those high temperatures by first producing electricity and then capturing waste heat for the production of process steam. Steam produced in this fashion for use in industrial processes or heating is usually at relatively low temperatures and pressures -- usually less than 200 psi and 300 to 400 degrees F.

Most of the cogeneration units currently available are diesel or gas turbine engines with heat exchangers in the 150 to 10,000 kw size range. Most of them are suitable for industrial applications and for heating large installations such as schools, businesses, and hotels. Small scale, 5 to 20 kw cogeneration units suitable for use in the home or small park, refuge, or hatchery have not yet been commercially developed. The only small scale cogeneration unit now under development is the Fiat Motor Corporation's electricity production and heating unit. This device consists of a small Fiat engine with heat exchangers coupled to a 15 kw electrical generator. The heat produced by the engine is captured by the heat exchangers and then used for space heat in buildings. But in addition to producing heat, the Fiat engine drives the electrical generator.

When installed, the Fiat system is intended to be economically self-sustaining. Electricity produced by the system would be sold to a local utility, and payment for the electricity would offset the cost of the fuel for the engine. Heat for the building would then be provided for free. Because the unit would be operating only when space heat was needed in the building, electricity for the building would be provided on a constant, reliable basis by the utility company, instead of from the cogeneration unit. This would allow shut-down of the unit when space heat was not required, without disruption of electric service. With a back-up battery storage system for use when the heater/generator was not running (see the section on Storage and Grid Integration), electricity could be obtained directly from the Fiat unit.

ADVANTAGES/DISADVANTAGES

Advantages

Cogeneration has numerous advantages. It saves fuel and capital and reduces waste; it requires little or no cooling water relative to conventional steam electric power generating systems; it can add substantial amounts of power generating capacity to the local grid thereby reducing utility peak capacity requirements and lowering rate increases designed to finance additional capacity; it can help decentralize power generating sources and increase the overall grid system's reliability, lower its distribution and transmission costs, and decrease the need for back-up power; it permits greater flexibility to plan future electrical generating capacity in light of uncertainties regarding electricity demand; and it can come "on line" much quicker than a conventional power plant (1 to 4 years rather than 8 to 10 for central station plants).

STORAGE and GRID INTEGRATION

INTRODUCTION

Several of the energy production technologies described in the on-site generation section can be used to produce electricity. They are wind, photovoltaics, hydropower, and cogeneration.

of fuel, the cost/kwh is generally reduced by using the greatest percentage of the electricity generated.

TECHNOLOGY - STORAGE

Batteries

finances the fuel for the generator. In some cases the proceeds from sales of surplus electricity significantly reduce fuel costs. In others, the revenue will not only make the cogeneration unit competitive with the existing system, but will also add capacity to the local utility.

If the unit is chosen to meet the electrical demand of a site, the reverse situation occurs. This is the least economical of the two cases in most instances because surplus heat is more difficult to market than surplus electricity. Furthermore, another heating system would have to be maintained. The second system would also operate at a lower efficiency than the cogeneration unit.

To make the preliminary assessment of cogeneration potential, you must be aware of both the heating and electrical requirements of your facility.

ECONOMICS

The following chart (Table 1) lists some of the cogeneration systems currently available (or soon to be available in the case of the Fiat unit) in a variety of sizes. Your site's power needs should be checked against the systems listed below to give you an idea of the costs involved with a cogeneration system. More detailed cost accounting procedures can be found in the References. The best procedure for calculating the cost and payback of a cogeneration unit at your site is to contact a manufacturer or consultant.

If your requirements are radically different from any of these, you may make economic estimates for a custom cogeneration system based on the following *rough figures*.

1. Cogeneration units cost approximately $400 per kw to install, regardless of size.
2. Cogeneration units rated under a million BTU/hr output cost $100,000 per 10^6 BTU/hr to install.
3. Cogeneration units rated at 100 million BTU/hr or greater cost $30,000 per 10^6 BTU/hr.

These figures relate to the systems presented in Table 1.

Payback periods must be calculated for each individual system, based on installed costs, reduced fuel costs, electricity sales to utilities, reduced electric costs, current electricity costs, and so on. An adequate cost/payback analysis is only possible after consultation with an engineer, manufacturer, or cogeneration expert and a utility representative. The yellow pages of the nearest large city telephone directory may be of assistance in locating local cogeneration system installers. In the eastern part of the U.S., such companies have been listed under *Fuel Companies*, some of which are diversifying by supplying diesel powered cogeneration systems.

applicable. Rapid change in the dimensions of the reservoir can also cause disruption of local flora and fauna. Smaller scale uses of the approach have been designed using standard water tanks instead of uphill reservoirs.

Compressed Air Storage

modern materials and innovative designs. Energy is stored in fast spinning, minimum friction wheels. They are still in the research phase and are not considered safe or currently available.

TECHNOLOGY - GRID INTEGRATION

Table 1. Cogeneration Systems

	HEAT				ELECTRICITY					
OUTPUT AND COST / TYPE SYSTEM	Maximum BTU/hr $x10^6$	Maximum BTU/yr $x10^9$	15 yr Life Cycle Cost $/MBTU	20 yr Life Cycle Cost $/MBTU	Rated Output kw	Maximum kwh/yr $x10^6$	Installed Cost $\$x10^3$	$/kw Installed	15 yr Life Cycle Cost $/kwh	20 yr Life Cycle Cost $/kwh
Internal Combustion Fiat 127	0.131	1.13	0.17	0.13	15	0.131	2.86	190	0.0015	0.0011
Diesel										
Cummins	0.53	4.58	0.78	0.59	120	1.05	54.0	450	0.0034	0.0026
Cummins	0.66	5.70	0.79	0.59	150	1.30	67.5	400-450	0.0035	0.0026
Cummins	1.20	10.37	0.72	0.54	280	2.40	112.0	300-400	0.0031	0.0023
Gas Turbine										
Solar Turbines	9.90	85.54	0.24	0.18	800	7.00	308.0	385	0.0029	0.0022
Solar Turbines	28.00	241.92	0.25	0.19	2,670	23.00	907.0	340	0.0026	0.0020
Solar Turbines	55.00	475.20	0.31	0.23	7,400	64.00	2,200.0	300	0.0023	0.0017

NOTE: Life cycle cost information is based on installed costs only.
No maintenance or operational costs are included.

COGENERATION

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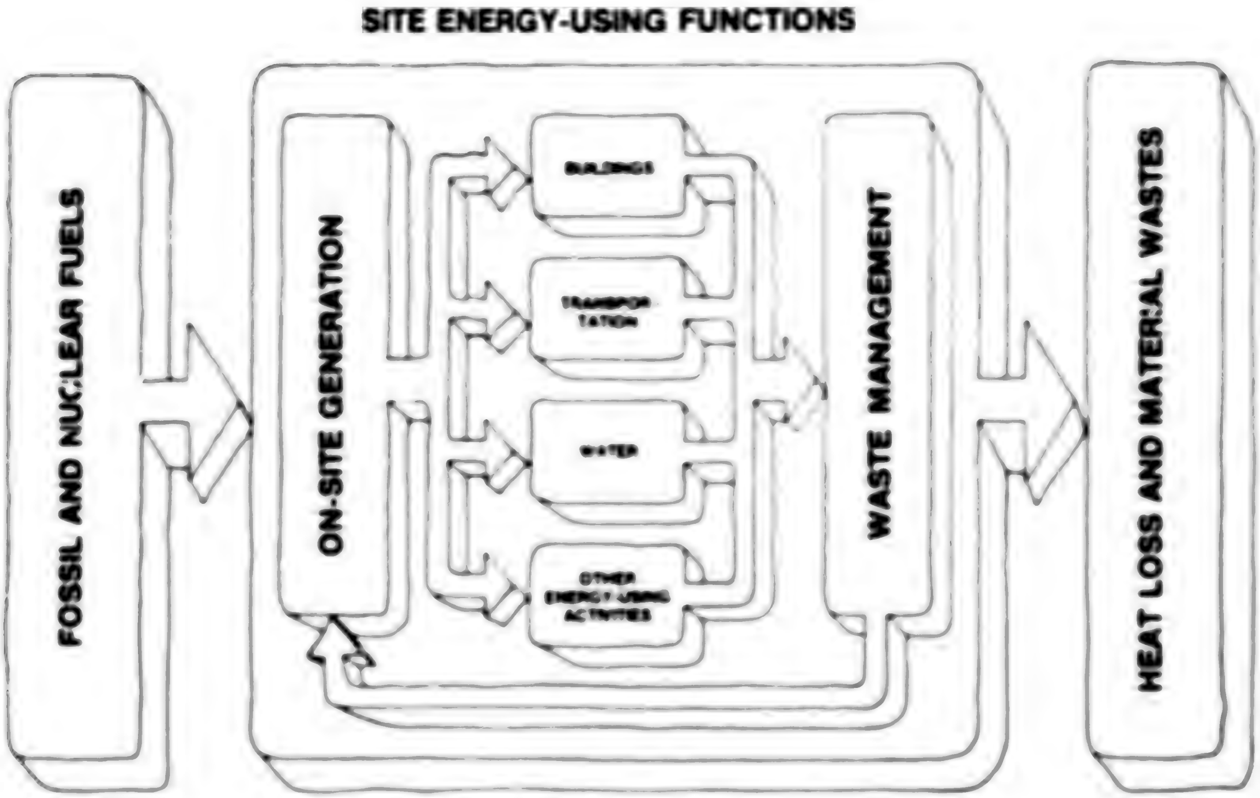
system in a year can be estimated based on the above information. For most systems there will be periods when the batteries are discharged, and the power source is unavailable. The cost of energy supplied by the storage system can be seen as the cost of storage system alone because the stored energy is

utilities commission.

The cost of the integration system must be balanced against the price paid by the utility for power channelled into the grid. These figures cannot be estimated precisely. A determination that a storage or integration system is needed must be based on an overall

Photovoltaics



STORAGE and GRID INTEGRATION

*Table 1. Costs and Efficiencies of Components for a Battery Storage System**

	Current		Future Potential	
	Cost	Efficiency	Cost	Efficiency
Batteries	$107/kwh	75%**	$33-50/kwh	85%**
Control System	$115/***	--	--	--

PHOTOVOLTAICS

INTRODUCTION

Photovoltaic cells ("photo" meaning light, "voltaic" meaning electricity) produce electricity directly from sunlight. Photocells have several advantages over traditional electrical production technologies, perhaps the most significant is that they have no moving parts. Photovoltaic electricity generation is a chemical process, rather than a mechanical one like those used in typical power plants. Besides offering an inherent simplicity, photovoltaic cells consume no fuel, their operation is pollution-free, and they are noiseless. They have long lifetimes, require little maintenance, operate at low, safe temperatures, and can be made from silicon, the second most abundant element in the Earth's crust. Photovoltaic cells are modular in nature and can thus be used for a wide spectrum of applications: modules of a few watts can power lights or radios in remote locations while huge integrated complexes can be erected to supply urban or industrial power needs with hundreds or thousands of Mega Watts.

Photovoltaic cells alone do not normally convert more than 10% of the sun's energy into electricity. But they could be used in conjunction with flatplate or concentrating solar thermal collectors to convert more of the total available radiation.

Despite the numerous advantages of photovoltaic cells, they are not currently in widespread use, due primarily to economic considerations. The first photovoltaic cells cost about $2,000 per Watt in the 1950s. As is true for most renewable energy hardware, the economics of solar photoelectricity is changing rapidly for the better. In the 1960s, manufacturers had photovoltaic cells available at about $200 a Watt. Cells are now available at less than $10 per Watt.

HISTORY

Solar cells are a part of the semiconductor revolution which began in the 1940s with the advent of the transistor. The products of this revolution permitted the widespread use of color television, pocket calculators, digital watches, electronic instrumentation, communication satellites, and modern computers. The solar cell offers as great a possibility for changing Western culture and economics as the latest advances in electronics technology. The first patents for solar cells were established in the early 1940s. Although the technology had been worked out on paper, the necessary breakthrough that allowed them to be manufactured did not occur until 1954, in the Bell Laboratories. By 1956, solar cells were being produced and were first applied to powering space satellites. The Vanguard TV-4, launched in early 1958, used a solar cell system which provided only 0.1 Watts of power. Solar cells were later used in the more sophisticated Telstar, Pioneer, Mariner, and communication satellites as well as in the manned Apollo and Skylab missions.

From the mid-1950s to 1973, virtually the only application for solar cells was in space. Some cells which were initially produced for the space program but did not meet NASA's rigid performance specifications, were used in remote terrestrial locations in the Arctic, Antarctic, and isolated mountain and desert regions. Solar cells are now used to power wristwatches, buoys, railroad signals, road signs, emergency telephones, irrigation pumps, and household appliances. Almost any device that runs on electricity can be powered by a grouping of photovoltaic cells.

Prices for solar cells have tumbled further and faster since 1973 than they had in the preceding 20 years. While costs for solar cell arrays in the 1950s reached $2,000 per Watt, from 1973 to

STORAGE and GRID INTEGRATION

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PHOTOVOLTAICS

1977 prices dropped from a high of $500 to approximately $11/Watt, a 45-fold decrease. Since 1977, prices have dropped even further. A recent request for proposals from the Department of Energy called for concentrating photovoltaic systems producing electricity at $2/Watt. Nine companies offered to meet this price level by the end of 1979. For most applications, the cost must drop to less than $1 in order to be competitive, but based on recent industry trends, this goal could be met as early as 1983. There are many applications, however, where the cells are already cost-effective.

Advances in cost reduction have been matched by advances in efficiency. In 1973, industry set a goal of achieving silicon solar cell efficiency of 10% by 1983. Two years later, two companies succeeded in making such cells. The increasing solar cell efficiency has the obvious importance of reducing costs.

TECHNOLOGY

Solar cells are made from many materials. Silicon, however, is the most common but there are cells under development that are made from cadmium sulfide and gallium arsenide as well. All work in basincally the same fashion -- solar cells are semiconductor crystals. A semiconductor is a basic element or mixture that neither conducts electricity (as does copper or aluminum) nor acts as an insulator (as does rubber). A semiconductor does not conduct electricity in the dark at low temperature, but will conduct in sufficient light and heat.

Two types of semiconductor silicon are used in silicon solar cells. One type has added boron atoms which give it a slight positive charge; the other type has added phosphorus or arsenic atoms which give it a slight negative charge. These two types of silicon are put together in a solar cell and a junction is formed with an electronic charge imbalance between the two layers. When sunlight hits the solar cells, photons strike the atoms in the cell and excite their electrons so that they escape the strong pull of the protons in their nuclei. The freed electrons move toward the positively charged silicon and then out into the electrical circuit wire to power the light, motor, or other device using electrical power. Essentially then, a solar cell converts a portion of the energy in sunlight into the movement of electrons around a circuit.

ADVANTAGES / DISADVANTAGES

There are advantages to photovoltaic cells and electrical generation systems that are so enticing that they are often spoken of as the ultimate fuel source or as someday being the perfect electrical generation technology. Since it is widely believed that the sun has at least another 2 billion years of productivity, one major advantage of solar cells is that there is an abundance of free fuel. The other important advantage is that there is no economy of scale in relation to photovoltaic arrays -- that is, it is no more expensive *per unit of usable output* for a household-sized photovoltaic system than a massive central photovoltaic plant generating enough energy to meet the needs of a whole state. There may, in fact, be diseconomies arising from transmission losses with large installations.

The disadvantages are relatively minor. The only real impediment to wide scale usage of solar cells is cost. Initial costs are not currently competitive with the stated costs of other electricity sources, although recent studies have revealed that there are substantial government subsidies to these other sources that make direct comparison unfair.(1) The price of photovoltaic cells is decreasing, and careful market stimulus is expected to make costs competitive within five years.(2)

[illegible]

Other disadvantages are similar to those associated with all intermittent energy sources, principally that demand for electricity does not change as the sun shines. Variability problems can be largely satisfied by using batteries and grid integration devices (see Storage and Grid Integration).

APPLICATIONS

Photovoltaics are applicable wherever electricity is in demand. There are three general types of photovoltaic electricity applications:

1. Direct Grid Subsidy -- where solar cells are used to reduce electric demand from the grid, thereby acting as negative appliances, using the grid as a storage medium for the electricity produced by the cells.
2. Battery Storage -- where solar cells produce electricity that is stored in batteries for use during periods when there is limited sunlight or none at all. Battery storage may also be necessary where remote locations make grid connections impossible or economically prohibitive.
3. Direct Use -- for direct current applications that require energy only when the sun is shining.

Solar cells are already in use for: powering refrigerators, lights, water pumps, and radios for the U.S. Forest Service; powering remotely located National Weather Service Stations and refrigerators for an Isle Royal National Park trail camp in Michigan and at the Papago Indian Village in Arizona; pumping well water and providing lighting in Indian reservations in New Mexico and Arizona; powering four water pumps that are part of a solar space and hot water heating system for a condominium in California; and powering an educational television system in Nigeria and irrigation pumps on a farm in Nebraska.

REQUIRED ENVIRONMENTAL CONDITIONS

The only critical conditions required for photovoltaic systems are sunshine and access to it. The cells are connected in *modules*, and several modules are generally connected as *panels*. These are generally the size of typical flat-plate collectors, 20 to 25 square feet. Panels are mounted with maximum access to the sun, on a daily basis and on a yearly basis. Orientation, then, is to true south, tilted to an angle roughly equivalent to one's degree of latitude. Any southfacing rooftop or clearing can be used for mounting photocells.

Figure 1 is a map giving a rough estimate of the solar intensity in the U.S. The higher the kilowatt hour per square meter, the better the chances of economical electrical production by solar cells. The amount received in the New England states is about two-thirds the amount received in the southwestern states. In every area, of course, the amount received varies with the weather, the time of day, and the season. Remember that the cost of electricity in your area also affects the economic viability of photovoltaics as an alternative.

PRODUCTION POTENTIAL

A small solar cell array can provide enough energy to power warning lights, emergency telephones, and similar apparatus in remote locations. A large solar cell array can power almost anything the local utility can. If alternating current (AC) is required, a power inverter must be used since solar cells produce direct current (DC). Because power is often needed when the sun is not shining, some type of storage system is necessary. Batteries are the most commonly used storage devices, although other systems are being developed.

PHOTOVOLTAICS

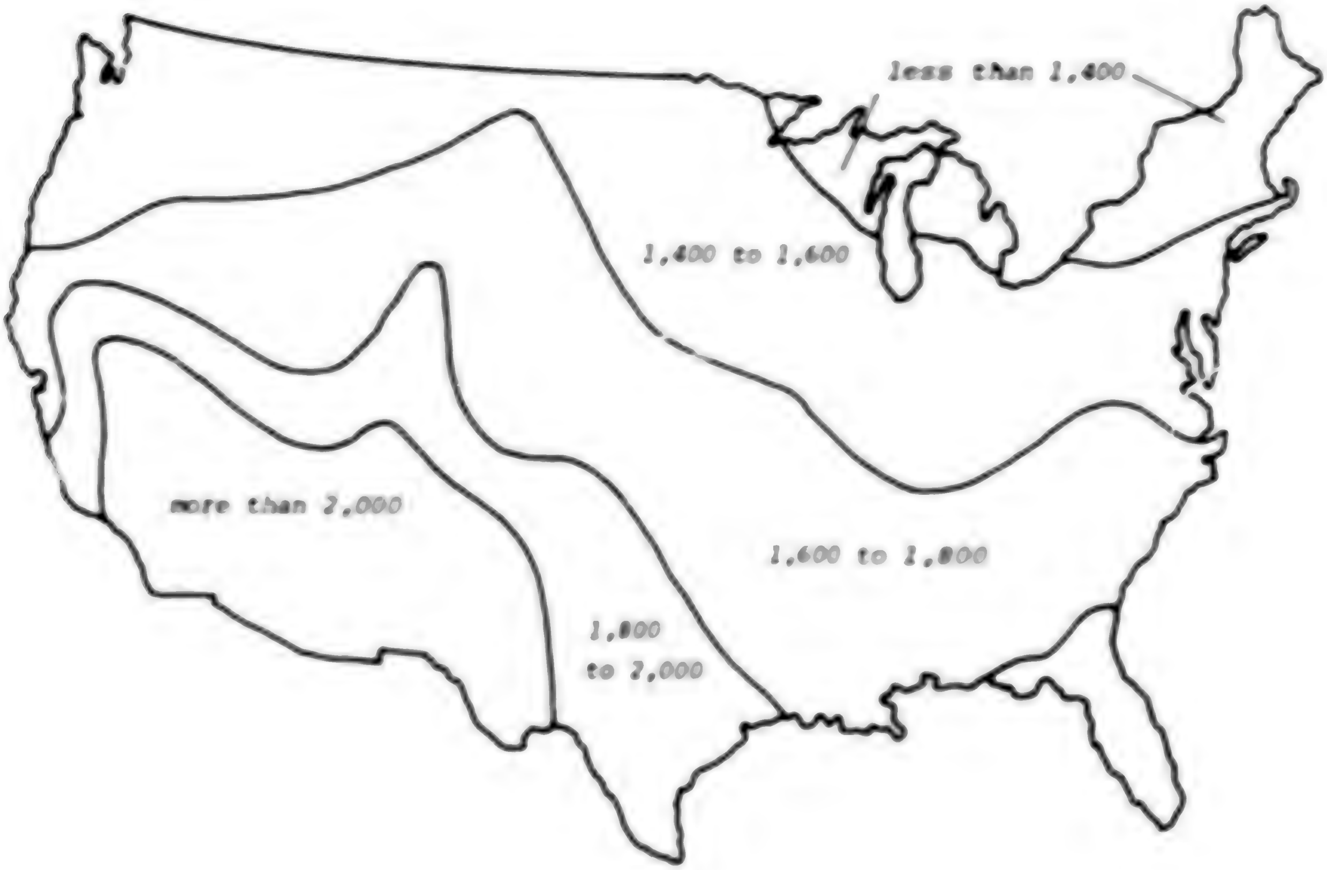

Figure 1. Amount of Solar Radiation Received each Year in Different Areas in the U.S. (kwh/m^2)

As noted above, the major deterrent to the use of solar cells is cost. Local production potential, then, is a function of: 1) your specific site demand, and 2) available space for south-facing arrays. To calculate array space, assume that for cells of 10% efficiency one square foot will produce 6 to 7 peak Watts with the regular, round cells, while the high density, rectangular cells will produce approximately 12 peak Watts.

The map gives some idea of the range of solar intensity in the U.S. The local weather bureau will be able to tell you the average number of sunny days at your particular site on an annual basis. If you are in a particularly cloudy or foggy region, it is possible that any type of solar cell arrangement would not be economical. Refer to the Solar Thermal section to determine whether your site has adequate solar insolation to permit use of a photovoltaic collecting system.

BEST DOCUMENT AVAILABLE

Table 1. Measures and Conversions

Mass	The U.S. System	Multiply	By	To obtain
		acres	43,560	square feet
	16 ounces = 1 pound	acres	4047	square meters
	2000 pounds = 1 short ton			

PHOTOVOLTAICS

ECONOMICS

When it has been determined what size solar cell system is needed, Table 1 should be consulted for the costs of various size systems. Because the price for solar cells is rapidly decreasing, projected costs are listed as well. The U.S. Department of Energy has projected the cost of solar cells to reach $.50 per Watt in the early to mid-1980s. Whether these projections are borne out will be apparent at the time of solar cell purchase. Manufacturers of solar cells such as are listed in Reference (3) can be consulted for current prices.

Table 1. Prices of Solar Cell Arrays 1978

	Cost (in bulk)				
Size of System	*1978*	*Projected #1*	*#2*	*#3(1985)*	*#4*
1 Watt	$12	$8	$2	50¢	25¢
5 Watts	60	40	10	$2.50	$1.25
10 Watts	120	80	20	$5	2.50
100 Watts	1,200	800	200	50	$25
500 Watts	6,000	4,000	1,000	250	125
1 kilowatt	12,000	8,000	2,000	500	250
5 kilowatts	60,000	40,000	10,000	2,500	1,250
10 kilowatts	120,000	80,000	20,000	5,000	2,500
100 kilowatts	$1.2 x 10^6	800,000	200,000	50,000	25,000
500 kilowatts	6.0 x 10^6	$4.0 x 10^6	$1.0 x 10^6	250,000	125,000
1 Mega Watt	12.0 x 10^6	8.0 x 10^6	2.0 x 10^6	500,000	250,000

Table 2 lists the costs per Watt and savings that could be accrued each year, assuming different utility rates. The time needed to pay back the initial capital investment is also listed. Whether it is economical or not to purchase and install a photovoltaic system will be determined by the unique needs, environment, finances, and values of each site. To use Table 2, find the local electric rate and read across to see the savings per year in dollars and payback period. Remember that this table only compares solar-cell-produced electricity with electricity being produced by the local utility. This assumes easy and low-cost access to the utility grid. If there is a connect charge to obtain utility electricty, it must be figured into the cost.

For solar cell systems larger than one Watt, multiply the cost per Watt and savings per year figures by the Watt rating that your site needs.

Some solar cell manufacturers offer a computer service that will help determine the best solar cell panel array, tilt angle, and size of battery storage for a particular power requirement and location. Those companies offering such services are listed in Reference (3), along with other manufacturers of photovoltaic cells.

PHOTOVOLTAICS

Table 2. Costs per Watt and Potential Savings

Cost per Watt	Utility Rate (¢/Watt hr.)	Savings per Year*	Payback Period	Utility Rate	Yearly Savings	Payback Period
$12.00	.02	$ 3.66	164 yr.	.04	$ 7.32	82 yr.
8.00	.02	3.66	109	.04	7.32	55
2.00	.02	3.66	27	.04	7.32	14
.50	.02	3.66	6.8	.04	7.32	3.4
.25	.02	3.66	3.4	.04	7.32	1.7
12.00	.06	10.98	55	.08	14.64	41
8.00	.06	10.98	36	.08	14.64	27
2.00	.06	10.98	9	.08	14.64	6.8
.50	.06	10.98	2.2	.08	14.64	1.7
.25	.06	10.98	1.1	.08	14.64	.85
12.00	.10	18.30	32.7	.25	45.75	13.1
8.00	.10	18.30	21.8	.25	45.75	8.7
2.00	.10	18.30	5.4	.25	45.75	2.1
.50	.10	18.30	1.3	.25	45.75	.54
.25	.10	18.30	.68	.25	45.75	.26

*To operate one 100-Watt light bulb 5 hours/day = .5 kwh/day = 183 kwh/yr. 50 Watts of solar cells operating 10 hours/day equals approximately 500 wh or .5 kwh/day.

PHOTOVOLTAICS

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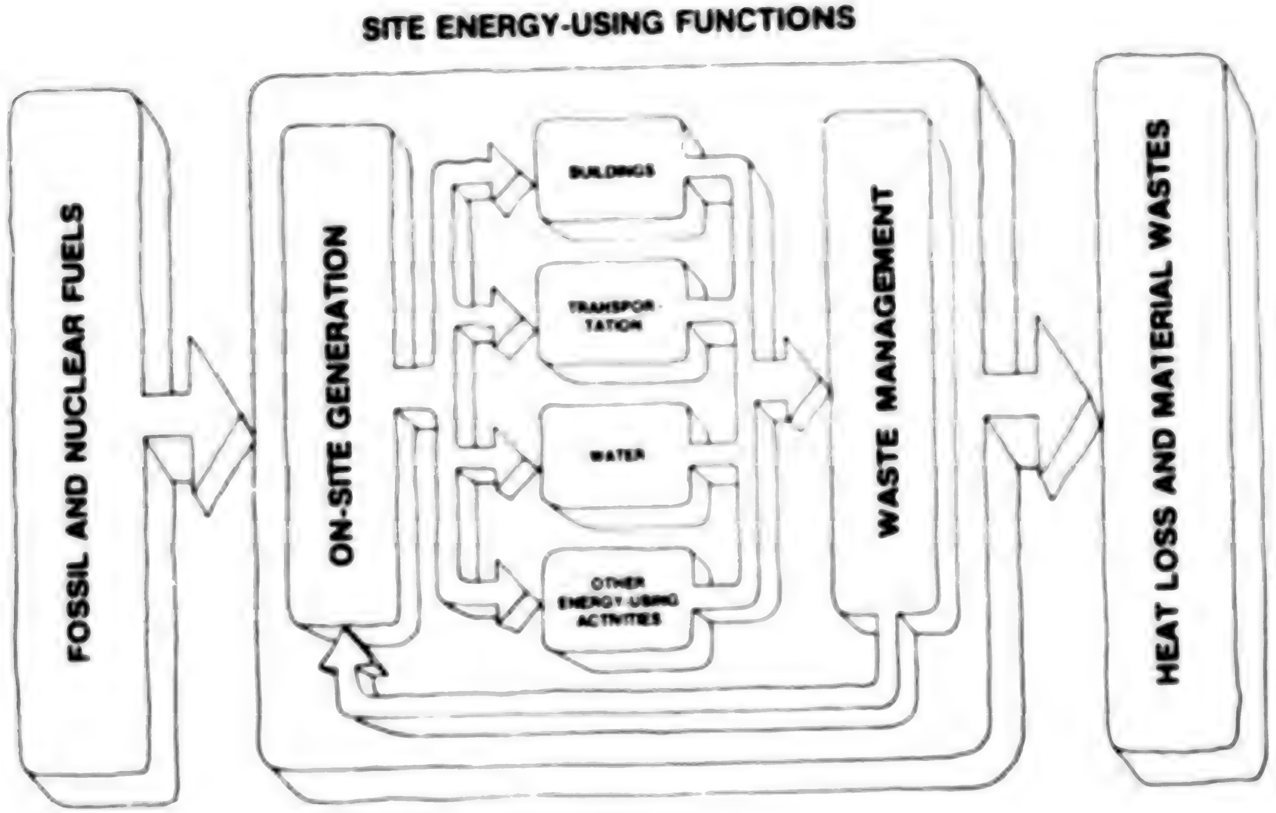
Storage and Grid Integration



STORAGE and GRID INTEGRATION

INTRODUCTION

Several of the energy production technologies described in the on-site generation section can be used to produce electricity. They are wind, photovoltaics, hydropower, and cogeneration. With the possible exceptions of hydropower and cogeneration, these energy sources are variable. Only rarely will their output exactly match power demand. This is because the wind does not always blow, nor does the sun always shine; it may also happen that the sun is shining and the wind blowing when the demand for electricity is low or nonexistent. The total average output, however, may be adequate or nearly adequate to meet local needs. A primary problem when considering the use of such variable energy sources is how to assure continuous energy supply. This is a problem of availability and storage.

The problem may be solved in one of two ways. The first solution is to store the energy when production exceeds demand and draw from that stored energy when demand exceeds production. The second is integration of the on-site power source into the local power grid. If it is impractical to interface directly with the local power grid, energy storage is the only option to assure continuous or near continuous availability of power. If the grid is accessible and local regulations permit, it may accept and distribute power from the source when production is greater than the on-site power requirements. The grid can then supply back-up power when output from the on-site source fails to meet the on-site demand. Thus the grid becomes an absorber or redistributor. In cases where grid integration is feasible, it is often more economical than energy storage, given the costs of energy storage systems such as battery packs.

Both the storage and the integration options help to maximize use of on-site power systems. Since the primary cost of electrical systems is the original capital investment rather than the cost of fuel, the cost/kwh is generally reduced by using the greatest percentage of the electricity generated.

TECHNOLOGY - STORAGE

Batteries

The only readily available, universally applicable storage device for energy once it has been converted to electricity is the rechargeable battery, or secondary cell. Secondary cells should not be confused with primary cells, such as flashlight batteries that cannot be recharged. Secondary cells store energy as electrochemical potential energy. This stored energy can be released as DC current at some later time. The batteries are modular storage elements in that they can be connected -- in series, or parallel, or both -- to yield any capacity and power output desired.

All on-site systems capable of producing electrical energy can be used to charge a secondary cell storage system. Battery charging systems should be designed to prevent:

1. large charging voltages which cause overheating,
2. low charging voltages which cause discharge of the battery, and
3. overcharging which causes electrolysis of the water in the electrolyte.

Voltage regulators designed to prevent these problems are available.

Pumped Water Storage

Pumped water storage is the only other storage method which uses "off-the-shelf" or available technology. Energy is stored before its conversion to electricity by pumping water uphill into a reservoir. When power is needed, the water is released to drive a hydroelectric generator. Such systems are in use at several large hydroelectric sites. Although effective, pumped water storage must be situated near a hydroelectric installation, and thus is not universally applicable. Rapid change in the dimensions of the reservoir can also cause disruption of local flora and fauna. Smaller scale uses of the approach have been designed using standard water tanks instead of uphill reservoirs.

Compressed Air Storage

Compressed air has been used as an energy storage medium at several European power stations. Off-peak power is used to run a compressor which pumps air into storage tanks. The air can then be released and expanded through a turbine to meet peak power demands. This type of system is not considered economically feasible on a small scale (i.e., less than 50 MW). Furthermore, compressed air systems cannot be constructed using off-the-shelf equipment, but must be specially designed and constructed for each application.

Hydrogen Energy

Electricity produced in excess of demand can be used to electrolyze water and yield hydrogen. This means the electric current is passed through water, breaking down the water molecules into separate hydrogen and oxygen molecules. Hydrogen, then, can be used as a fuel (an excellent natural gas substitute)whenever it is needed. Like natural gas, it is stored in tanks as a liquid or solid. The hydrogen can also be stored and later combined with oxygen in a fuel cell to produce electricity. Hydrogen has been used and stored safely in industry for years, but safe uses are expensive in spite of the basic simplicity of the conversion technologies. Small-scale hydrogen storage systems are now under testing and development, and show potential as a long-term option. However, they are currently impractical for most uses considered here.

Flywheels

Complex flywheel systems have been built for energy storage using modern materials and innovative designs. Energy is stored in fast spinning, minimum friction wheels. They are still in the research phase and are not considered safe or currently available.

TECHNOLOGY - GRID INTEGRATION

If the power grid is accessible, the least expensive method for maximizing the use of on-site power generation may be to feed excess electricity into the grid. This feeding process is only feasible if power produced by the local source is compatible with the power in the line. This compatibility requires that the output of the generator match the line power in phase, frequency, and voltage. The 60 cycle AC must be matched very accurately to avoid harming both the grid and the appliances.

These requirements pose a problem in integrating power from photovoltaic systems, wind powered generators, and other DC or highly variable AC systems. If DC power is produced, the output of the system must be fed through an inverter to obtain AC current before it is fed into the grid. Another option for constructing a wind powered generator producing AC power that is directly compatible with a grid involves the use of modified generators. Both the inverter and the modified generator are discussed below.

The requirement that output from the on-site generator match line power in phase, frequency, and voltage poses less of a problem in integrating hydroelectric and cogeneration systems than the more variable ones. This is because the power output from steam or hydroelectric turbines can be better controlled by adjusting the flow of steam or water through the turbines.

Inverters

One of the simplest and most inexpensive systems for integrating small scale variable sources with larger existing centralized electrical grids is called a synchronous inverter. When on-site electrical production capability is installed, the inverter integrates the electricity produced by the on-site source with the electricity supplied by the grid.

The first function of the inverter is to convert the DC electrical signal from the on-site generator to a 60-cycle AC signal and to synchronize the 60-cycle signal with that of the grid. Secondly, it regulates the two electrical supply sources in order to assure continuous supply. The inverter and a small and inexpensive solid state control ensure that when electrical supply from the on-site source is equal to demand from adjacent facilities, the electricity for these facilities comes from the local source. When demand from the facilities is greater than the supply generated on-site, the inverter allows the energy produced by the on-site source to be subsidized by electricity from the grid. At times when demand from the facility is smaller than that being produced on-site, the surplus electricity is fed into the grid, causing the meter to run backwards and to charge the utility for the additional energy.

There are three basic types of inverters: line commutated inverters, self-commutated inverters, and cyclo-inverters. We will consider only line commutated inverters here because the other two types are used in self-sufficient or independent situations and are more expensive and complex. Line commutated inverters can be used whenever a utility line is accessible. These inverters feed power into the electric grid using the line power as a reference. Usually, a synchronous inverter with a thyristor bridge circuit is used to feed current into the line. The output of the inverter is dependent upon the difference between the DC voltage produced by the power source and the AC line voltage. When the line voltage is greater in magnitude than the inverter voltage, the thyristors switch off to prevent power from flowing from the line into the DC source.

One example of a line commutated synchronous inverter is the Gemini Inverter, now available for use with wind generators. It links the output from the wind generator to a public utility power line. The varying voltage and frequency generated by the windmill is converted to the same type of electricity distributed by the utilities power grid.

Modified Generators

Generators capable of using a variable shaft speed to produce a constant frequency are not currently available on the commercial market. The technology has been demonstrated, however, and may be available in the next few years. Such generators will be of particular use in producing power from wind turbines.

Two such generator systems are: the field modulated generator and the Roesel generator. The field modulated system is currently being tested at Oklahoma State University. It uses AC power instead of DC power in the field coils of a synchronous generator. The output is then fed through a switching circuit and filtered to directly yield a frequency compatible with line power. When operable, the system will reduce the need for extensive grid interface devices.

The second system, the Roesel generator, uses a wound, laminated stator made of hard magnetizable material. On the stator is a magnetic imprinter which prints poles on the stator. The spacing of the poles constantly changes so that the output frequency is always proportional to the frequency of the current in the magnetic imprinter. The frequency in the magnetic imprinter is the same as the frequency of the line current, so the output of the generator can flow directly into the line.

Generators of this type are suitable for use with a wind turbine, but are not currently available off the shelf, though the required modifications are possible. Such generators are being manufactured by one Florida manufacturer, and the firm is considering the commercial production of a generator that would be compatible with wind turbines. Good technical descriptions of batteries, pump storage, electrolysis, inverters, and modified generators mav be found in sources listed in the Bibliography.

APPLICATIONS

Any time electrical energy is produced on-site, some storage or integration device will probably be desired. The two most practical and available approaches are batteries and inverters.

Batteries

Batteries are the only energy storage medium presented here, for several reasons. First, batteries are almost universally applicable. They are a viable storage option in a variety of cases. Second, the other techniques of energy storage mentioned above - pumped water storage, compressed air, hydrogen, and flywheels - are either not fully proven and available or are too dependent upon custom engineering work to be recommended for broad application at this time. However, for long-term uses, some of them may be feasible.

Modern industrial batteries will last as long as 15 years, but deep discharge will shorten their lifetime substantially. Required maintenance includes replenishing water and occasionally cleaning the contacts. New, sealed batteries may eliminate the first of these requirements. In order to maximize the life of the battery, energy usage should be minimized during the periods when the energy storage system is supplying power, and energy should be used directlv from the source (by-passing the battery) when it is available.

In order to avoid the need for an inverter, DC equipment must be used in conjunction with a battery storage system. Electric lights, radios, and resistance heating elements are naturally compatible with DC power, but rotating equipment (in electric motors) must be specifically selected for compatibility with DC power.

In estimating the storage requirements for a given use, it is important to consider both the peak power requirement (kw) and the energy storage requirement (kwh). The peak power requirement is the maximum load that would be experienced at a time when the storage system is being used. The energy storage requirement is the expected energy requirement during any one period when the battery system is providing power. This can be determined by multiplying the average power requirement of the load by the maximum expected down time (e.g. sunless or windless period).

A storage system designed to provide power 100% of the time is likely to be several times larger than a system which will provide power 85 to 95% of the time. Thus, it would be advisable to use a system designed for less than 100% back-up. Users of the system should be advised to minimize electrical consumption when electricity is being provided from the storage unit.

The required size of the storage system can be further reduced by using a load switching control system. Such a system will:

1. Extend the life expectancy of the storage battery system by preventing overcharging and overdraining.
2. Increase the utilization of on-site energy by transferring output to alternate loads when the storage batteries are fully charged.

If an alternate power source is available, a system can be added which will switch to that source when storage battery voltage is low.

In evaluating your need for either an energy storage or grid integration device, it is important to consider several questions. What are the approximate frequency and length of periods when your power source (e.g. wind or sun) is unavailable? Is 100% continuous power essential for your load? Is it only essential for part of your load? As mentioned above, it is advantageous to minimize your load when depending upon a storage system for power.

If an energy storage system is used, the amount of energy supplied by the system in a year can be estimated based on the above information. For most systems there will be periods when the batteries are discharged, and the power source is unavailable. The cost of energy supplied by the storage system can be seen as the cost of storage system alone because the stored energy is energy that would otherwise be wasted.

Inverters

Inverters are suited for use in any case where the local power grid is accessible, the load is large enough to merit connection with the grid, and consistent power is essential. Such inverters are currently connected to the power grid in 38 states. The precedent set by these applications should simplify many of the institutional problems associated with integrating a variable power source with the grid.

In some states, utilities have been open to the use of decentralized electric systems. This has been particularly true in public or quasi-public utilities where there is a reluctance to invest in new, large central power stations. In many other states, utilities have been willing to permit inverters as "experimental" devices, but in virtually every state where cases have been brought to public utilities commissions or courts, local and state government agencies have required utilities to cooperate. Most states now have established rates or prices that the utility must pay for the power it buys. It must be pointed out, however, that unless you plan to install a very large on-site generator, nearly all of what you produce will be used on your site so that the amount of electricity you sell to the grid is very small.

This is particularly true with small wind, hydro, and photovoltaic systems. Cogeneration and intermediate sized hydro systems may be more practically integrated by selling all electricity produced to the grid. Further information should be available from the state public utilities commission.

The cost of the integration system must be balanced against the price paid by the utility for power channelled into the grid. These figures cannot be estimated precisely. A determination that a storage or integration system is needed must be based on an overall estimate of payback and on required levels of continuous power.

ECONOMICS

Batteries currently cost about $80/kwh of capacity. If a 20 year system life is used as the basis of costs, this figure rises to $107/kwh. (See Table 1.) Table 2 presents information on inverter costs and efficiencies.

STORAGE and GRID INTEGRATION

Table 1. Costs and Efficiencies of Components for a Battery Storage System*

	Current		Future Potential	
	Cost	Efficiency	Cost	Efficiency
Batteries	$107/kwh	75%**	$33-50/kwh	85%**
Control System	$115/***	--	--	--
Housing	$\$15/\text{ft}^2$	--	$\$15/\text{ft}^2$	--

*Costs are based on a 20 year system life.

**Efficiencies can be increased by use of waste heat.

***A system that will switch to an alternate power source when the batteries are discharged will cost an additional $11

Table 2. Inverter Costs and Efficiencies

Inverters	Size	Cost	Efficiency	Payback
Gemini Synchronous Inverter	4 kw	$ 780	90%	*
	8 kw	1,450	90%	
	20 kw (3 phase)	5,500	90%	
	1000 kw (3 phase)	50,000	90%	
Delta Electronic Inverter	10 kw	10,000	90%	*
	300 kw	60,000		
Field Modulated Generator	future $/kw	150	80%	*
Roesel Generator	1 kw	2,000	75%	*
	7 kw	7,000	80%	

*Payback costs can be calculated using payback worksheet.

STORAGE and GRID INTEGRATION

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Appendices

APPENDIX A

BEST DOCUMENT AVAILABLE

Table 1. Measures and Conversions

Mass **The U.S. System**

16 ounces = 1 pound
2000 pounds = 1 short ton
2240 pounds = 1 long ton

The Metric System

10 milligrams (mg) = 1 centigram (cg)
10 centigrams = 1 decigram (dg) = 100 mg
10 decigrams = 1 gram (g) = 1,000 mg
10 grams = 1 dekagram (dkg)
10 dekagrams = 1 hectogram (hg) = 100 g
10 hectograms = 1 kilogram (kg) = 1,000 g
1,000 kilograms = 1 metric ton (t)

Volume **The U.S. System**

16 ounces (oz) = 1 pint (pt)
2 pints = 1 quart (qt)
4 quarts = 1 gallon (gal)

The Metric System

10 milliliters = 1 centiliter (cl)
10 centiliters = 1 deciliter (dl) = 100 ml
10 deciliters = 1 liter (l) = 1,000 ml
10 liters = 1 hectoliter (hl) = 100 l
10 hectoliters = 1 kiloliter (kl) = 1,000 l

Time

60 seconds = 1 minute
60 minutes = 1 hour
24 hours = 1 day
365.26 days = 1 year
10 years = 1 decade
100 years = 1 century
1000 years = 1 millenium

Circular

60 seconds of arc (″) = 1 minute of arc (′)
60 minutes of arc = 1 degree (°)
360 degrees = 1 full circle

Multiply	by	to obtain
acres	43,560	square feet
acres	4047	square meters
acres	1.562×10^{-3}	square miles
acres	5645.38	square varas
acres	4840	square yards
amperes	1/10	abamperes
amperes	3×10^{9}	statamperes
atmospheres	76.0	cms. of mercury
atmospheres	29.92	inches of mercury
atmospheres	33.90	feet of water
atmospheres	10,333	kgs. per sq. meter
atmospheres	14.0	
atmospheres	14.70	pounds per sq. inch
atmospheres	1.058	tons per sq. foot
British thermal units	0.2520	kilogram-calories
British thermal units	777.5	foot-pounds
British thermal units	3.927×10^{-4}	horse-power-hours
British thermal units	1054	joules
British thermal units	107.5	kilogram-meters
British thermal units	2.928×10^{-4}	kilowatt-hours
B.t.u. per min	12.96	foot-pounds per sec
B.t.u. per min	0.02356	horse-power
B.t.u. per min	0.01757	kilowatts
B.t.u. per min	17.57	watts
B.t.u. per sq. ft. per min	0.1220	watts per sq. inch
bushels	1.244	cubic feet
bushels	2150	cubic inches
bushels	0.03524	cubic meters
bushels	4	pecks
bushels	64	pints (dry)
bushels	32	quarts (dry)
centimeters	0.3937	inches
centimeters	0.01	meters
centimeters	393.7	mils
centimeters	10	millimeters
centimeter-grams	980.7	centimeter-dynes
centimeter-grams	10^{-5}	meter-kilograms
centimeter-grams	7.233×10^{-5}	pound-feet
centimeters of mercury	0.01316	atmospheres
centimeters of mercury	0.4461	feet of water
centimeters of mercury	136.0	kgs. per sq. meter
centimeters of mercury	27.85	pounds per sq. foot

BEST DOCUMENT AVAILABLE

Table 1. Measures and Conversions (continued)

Multiply	by	to obtain
centimeters of mercury	0.1934	pounds per sq. inch
centimeters per second	·969	feet per minute
centimeters per second	0.03281	feet per second
centimeters per second	0.036	kilometers per hour
centimeters per second	0.6	meters per minute
centimeters per second	0.02237	miles per hour
centimeters per second	3.728×10^{-4}	miles per minute
cubic centimeters	3.531×10^{-5}	cubic feet
cubic centimeters	6.102×10^{-2}	cubic inches
cubic centimeters	10^{-6}	cubic meters
cubic centimeters	1.308×10^{-6}	cubic yards
cubic centimeters	2.642×10^{-4}	gallons
cubic centimeters	10^{-3}	liters
cubic centimeters	2.113×10^{-3}	pints (liq.)
cubic centimeters	1.057×10^{3}	quarts (liq.)
cubic feet	62.43	pounds of water
cubic feet	2.832×10^{4}	cubic cms.
cubic feet	1728	cubic inches
cubic feet	0.02832	cubic meters
cubic feet	0.03704	cubic yards
cubic feet	7.481	gallons
cubic feet	28.32	liters
cubic feet	59.84	pints (liq.)
cubic feet	29.92	quarts (liq.)
cubic feet per minute	472.0	cubic cms. per sec.
cubic feet per minute	0.1247	gallons per sec.
cubic feet per minute	0.4720	liters per second
cubic feet per minute	62.4	lbs. of water per min.
cubic feet per minute	472.0	cubic cms. per sec.
cubic feet per minute	0.1247	gallons per sec.
cubic feet per minute	0.4720	liters per second
cubic feet per minute	62.4	lbs. of water per min.
cubic inches	16.39	cubic centimeters
cubic inches	5.787×10^{-4}	cubic feet
cubic inches	1.639×10^{-5}	cubic meters
cubic inches	2.143×10^{-5}	cubic yards
cubic inches	4.329×10^{-3}	gallons
cubic inches	1.639×10^{-2}	liters
cubic inches	0.03463	pints (liq.)
cubic inches	0.01732	quarts (liq.)
cubic yards	7.646×10^{5}	cubic centimeters
cubic yards	27	cubic feet
cubic yards	46,656	cubic inches

Multiply	by	to obtain
cubic yards	0.7646	cubic meters
cubic yards	202.0	gallons
cubic yards	764.6	liters
cubic yards	1616	pints (liq.)
cubic yards	807.9	quarts (liq.)
cubic yards per minute	0.45	cubic feet per sec.
cubic yards per minute	3.367	gallons per second
cubic yards per minute	12.74	liters per second
degrees (angle)	60	minutes
degrees (angle)	0.01745	radians
degrees (angle)	3600	seconds
dynes	1.020×10^{3}	grams
dynes	7.233×10^{-5}	poundals
dynes	2.248×10^{-6}	pounds
ergs	9.486×10^{11}	British thermal units
ergs	1	dyne-centimeters
ergs	1.020×10^{-8}	gram-centimeters
ergs	10^{-7}	joules
ergs	2.390×10^{-11}	kilogram-calories
ergs	1.020×10^{-8}	kilogram-meters
feet	30.48	centimeters
feet	12	inches
feet	0.3048	meters
feet	.36	varas
feet	1/3	yards
feet of water	0.02950	atmospheres
feet of water	0.8826	inches of mercury
feet of water	304.8	kgs. per sq. meter
feet of water	62.43	pounds per sq. ft.
feet of water	0.4335	pounds per sq. inch
foot-pounds	1.286×10^{-3}	British thermal units
foot-pounds	1.356×10^{7}	ergs
foot-pounds	5.050×10^{-7}	horse-power-hours
foot-pounds	1.356	joules
foot-pounds	3.241×10^{-4}	kilogram-calories
foot-pounds	0.1383	kilogram-meters
foot-pounds	3.766×10^{-7}	kilowatt-hours
foot-pounds per min.	1.286×10^{-3}	B.t. units per minute
foot-pounds per min.	0.01667	foot-pounds per sec.
foot-pounds per min.	3.241×10^{-4}	kg.-calories per min.
foot-pounds per min.	2.260×10^{-5}	kilowatts
foot-pounds per sec.	7.717×10^{-2}	B.t. units per minute
foot-pounds per sec.	1.818×10^{-3}	horse-power

Table 1. Measures and Conversions
(continued)

Multiply	**by**	**to obta**	**Multiply**	**by**	**to obtain**
foot-pounds per sec.	1.356×10^{-3}	kilowatts	kg. calories per min.	0.06972	kilowatts
horse-power	33,000	foot-pounds per min.	kilometers	10^5	centimeters
horse-power	550	foot-pounds per sec.	kilometers	3281	feet
horse-power	1.014	horse-power (metric)	kilometers	10^3	meters
horse-power	10.70	kg. calories per min.	kilometers	0.6214	miles
horse-power	0.7457	kilowatts	kilometers	1093.6	yards
horse-power	745.7	watts	kilowatts	56.92	B.t. units per min.
horse-power (boiler)	33,520	B.t.u. per hour	kilowatts	4.425×10^4	foot-pounds per mi
horse-power (boiler)	9.804	kilowatts	kilowatts	737.6	foot-pounds per se
horse-power-hours	2547	British thermal units	kilowatts	1.341	horse-power
horse-power-hours	1.98×10^6	foot-pounds	kilowatts	14.34	kg.-calories per min.
horse-power-hours	2.684×10^6	joules	kilowatts	10^3	watts
horse-power-hours	641.7	kilogram-calories	kilowatt-hours	3415	British thermal units
horse-power-hours	2.737×10^5	kilogram-meters	kilowatt-hours	2.655×10^6	foot-pounds
horse-power-hours	0.7457	kilowatt-hours	kilowatt-hours	1.341	horse-power-hours
inches	2.540	centimeters	kilowatt-hours	3.6×10^6	joules
inches	10^3	mils	kilowatt-hours	860.5	kilogram-calories
inches	.03	varas	kilowatt-hours	3.671×10^5	kilogram-meters
inches of mercury	0.03342	atmospheres	$\log^{10} N$	2.303	$\log_e N$ or ln N
inches of mercury	1.133	feet of water	$\log^{e} N$ or ln N	0.4343	$\log_{10} N$
inches of mercury	345.3	kgs. per sq. meter	meters	100	centimeters
inches of mercury	70.73	pounds per sq. ft.	meters	3.2808	feet
inches of mercury	0.4912	pounds per sq. in.	meters	39.37	inches
inches of water	0.002458	atmospheres	meters	10^{-3}	kilometers
inches of water	0.07355	inches of mercury	meters	10^3	millimeters
inches of water	25.40	kgs. per sq. meter	meters	1.0936	yards
inches of water	0.5781	ounces per sq. in.	miles	1.609×10^5	centimeters
inches of water	5.204	pounds per sq. ft.	miles	5280	feet
inches of water	0.03613	pounds per sq. in.	miles	1.6093	kilometers
kilograms	980,665	dynes	miles	1760	yards
kilograms	10^3	grams	miles	1900.8	varas
kilograms	70.93	poundals	miles per hour	44.70	centimeters per sec.
kilograms	2.2046	pounds	miles per hour	88	feet per minute
kilograms	1.102×10^{-3}	tons (short)	miles per hour	1.467	feet per second
kilogram-calories	3.968	British thermal units	miles per hour	1.6093	kilometers per hour
kilogram-calories	3086	foot-pounds	miles per hour	0.8684	knots per hour
kilogram-calories	1.558×10^{-3}	horse-power-hours	miles per hour	26.82	meters per minute
kilogram-calories	4183	joules	miles per hour per sec.	44.70	cms. per sec. per sec.
kilogram-calories	426.6	kilogram-meters	miles per hour per sec.	1.467	ft. per sec. per sec.
kilogram-calories	1.162×10^{-3}	kilowatt-hours	miles per hour per sec.	1.6093	kms. per hr. per sec.
kg.-calories per min.	51.43	foot-pounds per sec.	miles per hour per sec.	0.4470	M. per sec. per sec.
kg.-calories per min.	0.09351	horse-power	months	30.42	days
			months	730	hours

Table 1. Measures and Conversions
(continued)

Multiply	by	to obtain
months	43,800	minutes
months	2.628×10^{6}	seconds
ounces	8	drams
ounces	437.5	grains
ounces	28.35	grams
ounces	0.625	pounds
ounces per square inch	0.0625	pounds per sq. inch
pints (dry)	33.60	cubic inches
pints (liq.)	28.87	cubic inches
pounds	444,824	dynes
pounds	7000	grains
pounds	453.6	grams
pounds	16	ounces
pounds	32.17	poundals
pounds of water	0.01602	cubic feet
pounds of water	27.68	cubic inches
pounds of water	0.1198	gallons
pounds of water per min.	2.669×10^{-4}	cubic feet per sec
pounds per cubic foot	0.01602	grams per cubic cm
pounds per cubic foot	16.02	kgs. per cubic meter
pounds per cubic foot	5.787×10^{-4}	pounds per cubic in
pounds per cubic foot	5.456×10^{-9}	pounds per mil foot
pounds per square foot	0.01602	feet of water
pounds per square foot	4.882	kgs. per sq. meter
pounds per square foot	6.944×10^{-3}	pounds per sq. inch
pounds per square inch	0.06804	atmospheres
pounds per square inch	2.307	feet of water
pounds per square inch	2.036	inches of mercury
pounds per square inch	703.1	kgs. per sq. meter
pounds per square inch	144	pounds per sq. foot
quarts	32	fluid ounces
quarts (dry)	67.20	cubic inches
quarts (liquid	57.75	cubic inches
rods	16.5	feet
square centimeters	1.973×10^{5}	circular mils
square centimeters	1.076×10^{-3}	square feet
square centimeters	0.1550	square inches
square centimeters	10^{-6}	square meters
square centimeters	100	square millimeters
square feet	2.296×10^{-5}	acres
square feet	929.0	square centimeters
square feet	144	square inches
square feet	0.09290	square meters
square feet	3.587×10^{-8}	square miles
square feet	.1296	square varas
square feet	1/9	square yards
square inches	1.273×10^{6}	circular mils
square inches	6.452	square centimeters
square inches	6.944×10^{-3}	square feet
square inches	10^{6}	square mils
square inches	645.2	square millimeters
square miles	640	acres
square miles	27.88×10^{6}	square feet
square miles	2.590	square kilometers
square miles	3,613,040.45	square varas
square miles	3.098×10^{6}	square yards
square yards	2.066×10^{-4}	acres
square yards	9	square feet
square yards	0.8361	square meters
square yards	3.228×10^{-7}	square miles
square yards	1.1664	square varas
temp. (degs. C.) + 17.8	1.8	temp. (degs. Fahr.)
temp. (degs. F.) — 32	5/9	temp. (degs. Cent.)
tons (long)	2240	pounds
tons (short)	2000	pounds
yards	.9144	meters

BEST DOCUMENT [illegible]

Table 2. Energy Equivalents

ENERGY EQUIVALENTS		Coal (tons)	Oil (bbl)	Natural gas (ft^3)	U^{235} (g)	Deuterium (g)
1 kilowatt hour		1.16×10^{-4}	5.88×10^{-4}	3.41	4.35×10^{-5}	1.51×10^{-5}
1 joule	is derived from	3.23×10^{-11}	1.63×10^{-10}	10^{-6}	1.20×10^{-11}	4.21×10^{-12}
1 calorie		1.35×10^{-10}	6.84×10^{-10}	3.97×10^{-6}	5.82×10^{-11}	1.76×10^{-11}
1 watt year		1.02×10^{-3}	5.16×10^{-3}	30	3.80×10^{-4}	1.33×10^{-11}
1 Btu		3.41×10^{-8}	1.72×10^{-7}	10^{-3}	1.28×10^{-8}	4.44×10^{-9}
1 metric ton coal (10^6 g)		1	5	2.94×10^{4}	0.37	0.13
1 barrel oil (42 gal)		0.2	1	5800	0.07	0.026
1 cubic foot natural gas	is equivalent to	3.41×10^{-5}	1.72×10^{-4}	1	1.27×10^{-5}	4.44×10^{-6}
1 gram U^{235}		2.7	13.5	7.84×10^{4}	1	3.5
1 gram deuterium		7.7	39	2.25×10^{5}	2.9	1
		kWh	J	cal	W-yr	Btu
1 kilowatt hour	equals	1	3.80×10^{6}	8.60×10^{5}	0.114	3410
1 joule	equals	2.78×10^{-7}	1	0.239	3.17×10^{-8}	9.48×10^{-4}
1 calorie	equals	1.16×10^{-6}	4.18	1	1.33×10^{-6}	3.97×10^{-3}
1 wattyear	equals	8.77	3.16×10^{7}	7.54×10^{6}	1	2.99×10^{4}
1 Btu	equals	2.93×10^{-4}	1054	252	3.21×10^{-5}	1
1 metric ton coal (10^6 g)	yields	8600	3.10×10^{10}	7.40×10^{9}	981	2.93×10^{7}
1 barrel oil (42 gal)	yields	1700	6.12×10^{9}	1.46×10^{9}	194	5.80×10^{6}
1 cubic foot natural gas	yields	0.29	1.05×10^{6}	2.52×10^{5}	0.033	1000
1 gram U^{235}	yields	2.30×10^{4}	8.28×10^{10}	1.98×10^{10}	2620	7.84×10^{7}
1 gram deuterium	yields	6.60×10^{4}	2.38×10^{11}	5.68×10^{10}	7.53×10^{3}	2.25×10^{8}

APPENDIX B

Table 1

SPECIFIC ENERGY USE CHART

(A)	(B)	(C)	(D)	(E)
Appliance/Machine	Avg. Watts	Hrs. Used/mo	kwh/mo	kwh/yr
EXAMPLE: Air Cond.	860	150	129 (3 mos)	387
Total				

Steps for completing table 1.

Step 1: In column A, list each appliance/machine for which a proposed on-site generation system will supply power at your park, refuge or hatchery.

Step 2: From table 2, determine the average watts required for each item listed in column A and write in column B. For those appliances/machines not listed in table 2, read from manufacturer's label on the appliance/machine.

Step 3: Estimate the number of hours the appliance/machine will be operating each month and write the number in column C.

Step 4: Multiply the figure in column B by the figure in column C and divide by 1,000 to convert to kilowatt hours per month, and write in column D.

Step 5: Multiply the figure in column D by the number of months per year the equipment is expected to be used and write the answer in column E.

The total in column B is the peak power that would be drawn at any time all the items listed in column A were on and operating. If the on-site generator is expected to furnish enough power to operate all the equipment at one time, it would have to be sized to handle not only the peak power of the items listed above, but would have to produce enough power to cover transmission line and control system losses.

BEST DOCUMENT [illegible]

Table 2. Kilowatt Ratings of Appliances

KILOWATT RATINGS OF APPLIANCES

Name	Watts	Hrs/Mo	KWHRS/Mo
Air conditioner, central			620*
Air conditioner, window	1566	74	116*
Battery charger			1*
Blanket	190	80	15
Blanket	50-200		15
Blender	350	3	1
Bottle sterilizer	500		15
Bottle warmer	500	6	3
Broiler	1436	6	8.5
Clock	1-10		1.4*
Clothes drier	4800	20	92*†
Clothes drier, electric heat	4856	18	86*†
Clothes drier, gas heat	325	18	6*†
Clothes washer			8.5*
Clothes washer, automatic	250	12	3*
Clothes washer, conventional	200	12	2*†
Clothes washer, automatic	512	17.3	9*
Clothes washer, ringer	275	15	4*†
Clippers	40-60		½
Coffee maker	800	15	12
Coffee maker, twice a day			8
Coffee percolator	300-600		3-10
Coffee pot	894	10	9
Cooling, attic fan	1/6-3/4HP		60-90*†
Cooling, refrigeration	3/4-1½ ton		200-500*
Corn popper	460-650		1
Curling iron	10-20		½
Dehumidifier	300-500		50*
Dishwasher	1200	30	36*
Dishwasher	1200	25	30*
Disposal	375	2	1*
Disposal	445	6	3*
Drill, electric, ¼"	250	2	5
Electric baseboard heat	10,000	160	1600
Electrocuter, insect	5-250		1*
Electronic oven	3000-7000		100*
Fan, attic	370	65	24*†
Fan, kitchen	250	30	8*†
Fan, 8"-16"	35-210		4-10*†
Lawnmower	[illegible]		[illegible]
Lighting	[illegible]		10-40
Lights, 6 room house in winter			60
Light bulb, 75	75	120	9
Light bulb, 40	40	120	4.8
Mixer	125	6	1
Mixer, food	50-200		1
Movie projector	300-1000		
Oil burner	500	100	50*
Oil burner			50*
Oil burner, 1/8 HP	250	64	16*
Pasteurizer, ½ gal	1500		10-40
Polisher	350	6	2
Post light, dusk to dawn			35
Power tools			3
Projector	500	4	2*
Pump, water	450	44	20*†
Pump, well			20*†
Radio			8
Radio, console	100-300		5-15*
Radio, table	40-100		5-10*
Range	8500-1600		100-150
Range, 4 person family			100
Record player	75-100		1-5
Record player, transistor	60	50	3*
Record player, tube	150	50	7.5*
Recorder, tape	100	10	1*
Refrigerator	200-300		25-30*
Refrigerator, conventional			83*
Refrigerator freezer	200	150	30*
Refrigerator freezer 14 cu ft	326	290	95*
Refrigerator freezer frost free	360	500	180*
Roaster	1320	30	40
Rotisserie	1400	30	42*
Sauce pan	300-1400		2-10
Sewing machine	30-100		½-2
Sewing machine	100	10	1
Shaver	12		1/10
Skillet	1000-1350		5-20
Skil Saw	1000	6	6
Sunlamp	400	10	4
Swnlo	279	5.4	1.5

Sheep shearing	fractional	1½ per 100 sheep
Silo unloader	2-5 HP	4-8 per ton*
Silage conveyer	1-3 HP	1-4 per ton*
Stock tank heater	200-1500 watts	varies widely
Yard lights	100-500 watts	10 per mo
Ventilation	1/6-1/3 HP	2-6 per day*† per 20 cows
IN THE MILKHOUSE		
Milk cooling	½-5 HP	1 per 100 lbs. milk*
Space heater	1000-3000	800 per year
Ventilating fan	fractional	10-25 per mo *†
Water heater	1000-5000	1 per 4 gal
FOR POULTRY		
Automatic feeder	¼-½ HP	10-30 KWHR/mo*†
Brooder	200-1000 watts	¼-1½ per chick per season
Burglar alarm	10-60 watts	2 per mo *
Debeaker	200-500 watts	1 per 3 hrs
Egg cleaning or washing	fractional HP	1 per 2000 eggs*†
Egg cooling	1/6-1HP	1½ per case*
Night lighting	40-60 watts	10 per mo per 100 birds
Ventilating fan	50-300 watts	1-1½ per day*† per 1000 birds
Water warming	50-700 watts	varies widely
FOR HOGS		
Brooding	100-300 watts	35 per brooding period/litter
Ventilating fan	50-300 watts	¼-1½ per day*†
Water warming	50-1000 watts	30 per brooding period/litter
FARM SHOP		
Air compressor	¼-½ HP	1 per 3 hr *
Arc welding	37½ amp	100 per year*
Battery charging	600-750 watts	2 per battery charge*
Concrete mixing	½-2 HP	1 per cu. yd.*†
Drill press	1/6-1 HP	½ per hr *†
Fan, 10"	35-55 watts	1 per 20 hr *†
Grinding, emergy wheel	1/4-1/3 HP	1 per 3 hr *†
Heater, portable	1000-3000 watts	10 per mo
Heater, engine	100-300 watts	1 per 5 hr
Lighting	50-250 watts	4 per mo
Lathe, metal	¼-1 HP	1 per 3 hr

Table 2. Kilowatt Ratings of Appliances (continued)

Food blender	200 300		1
Food warming tray	350	20	7
Footwarmer	50 100		1
Floor polisher	200 400		1
Freezer, food, 5 30 cu ft	300 800		30 125*
Freezer, ice cream	50 300		½
Freezer	350	90	32*
Freezer, 15 cu ft	440	330	145*
Freezer, 14 cu ft			140*
Freezer, frost free	440	180	57*
Fryer, cooker	1000 1500		5
Fryer, deep fat	1500	4	6
Frying pan	1196	12	15
Furnace electric control	10 30		10*
Furnace, oil burner	100 300		25 40*
Furnace, blower	500 700		25 100*†
Furnace, stoker	250 600		3 60*†
Furnace, fan			32*†
Garbage disposal equipment	1/4 1/3 HP		½*
Griddle	450 1000		5
Grill	650 1300		5
Hair drier	200 1200		½ 6*
Hair drier	400	5	2*
Heat lamp	125 250		2
Heater, aux.	1320	30	40
Heater, portable	660 2000		15 30
Heating pad	25 150		1
Heating pad	65	10	1
Heat lamp	250	10	3
Hi Fi Stereo			9*
Hot plate	500 1650		7 30
House heating	8000 15,000		1000 2500
Humidifier	500		5 15*
Iron	1100	12	13
Iron			12
Iron, 18 hrs/month			13
Ironer	1500	12	18
Knife sharpener	125		¼*
Television	200 315		15 30*
TV BW	200	120	24*
TV BW	237	110	25*
TV color	350	120	42*
TV color			100*
Toaster	1150	4	5
Typewriter	30	15	5*
Vacuum cleaner	600	10	6
Vacuum cleaner, 1 hr/wk			4
Vaporizer	200 500		2 5
Waffle iron	550 1300		1 2
Washing machine, 12 hrs mo			9*
Washer, automatic	300 700		3 8*
Washer, conventional	100 400		2 4*
Water heater	4474	89	400
Water heater	1200 7000		200 300
Water pump (shallow)	½HP		5 20*†
Water pump (deep)	1/3 1 HP		10 60*†

AT THE BARN

Name	Capacity HP or watts	Est. KWHR
Barn cleaner	2 5 HP	120/yr *
Clipping	fractional	1/10 per hr
Corn, ear crushing	1 5 HP	5 per ton*
Corn, ear shelling	¼ 2	1 per ton*†
Electric fence	7 10 watts	7 per mo *†
Ensilage blowing	3 5	½ per ton
Feed grinding	1 - 7½	½ 1½ per 100 lbs *†
Feed mixing	½ 1	1 per ton*†
Grain cleaning	¼ ½	1 per ton/bu*†
Grain drying	1 7½	5 7 per ton*†
Grain elevating	¼ 5	4 per 1000 bu*†
Hay curing	3 7½	60 per ton*
Hay hoisting	½ 1	1/3 per ton*†
Milking, portable	¼ ½	1½ per cow/mo *†
Milking, pipeline	½ 3	2½ per cow/mo *†
Lathe, wood	¼ - 1 HP	1 per 3 hr
Sawing, circular		
8" - 10"	1/3 - 1/2 HP	1/2 per hr
Sawing, jig	1/4 - 1/3 HP	1 per 3 hr
Soldering iron	60 500 watts	1 per 5 hr
MISCELLANEOUS		
Farm chore motors	½ - 5	1 per HP per hr
Insect trap	25 40 watts	1/3 per night
Irrigating	1 HP up	1 per HP per hr
Snow melting, sidewalk and steps, heating cable imbedded in concrete	25 watts per sq ft	2 5 per 100 sq ft per hr
Soil heating, hotbed	400 watts	1 per day per season
Wood sawing	1 5 HP	2 per cord

Symbol Explanation

*AC power required

†Normally AC but convertible to DC

Notes: Lighting in this table is assumed to be incandescent—if flourescent, the wattage bulbs consume the same power but deliver 3 times as much light. Flourescent bulbs also require AC but can be converted to DC.

These figures can be cut by 50% with conservation of electricity.

1) Sources for this table represent a conglomerate of several separate tables taken from:

a) Northern States Power Co. Mpls, Mn
b) University of Minnesota Agricultural Extension Service
c) Seattle City Light, Seattle, Washington
d) Energy Conservation Techniques, National Bureau of Standards
e) Garden Way Labs
f) Henry Clews
g) Real Gas and Electric

APPENDIX C

APPENDIX C

To calculate the cost payback period for any on-site generation system you may wish to install, use Table 1, with the following steps.

Step 1: List the new on-site generation system you plan to install in column A.

Step 2: In column B, list the total expected cost of the equipment, including installation and start-up fees.

Step 3: In column C, list the difference in operation and maintenance costs expected per year, if any. The old system may have required heavy maintenance, on a daily or weekly basis, and a great deal of downtime for replacement of parts. The new system may require once a month lubrication or periodic inspections, therefore, the difference may be a negative number.

Step 4: In column D, list the amount of conventional fuel you have displaced by utilizing the new on-site generation system. Electricity in kilowatt hours, oil or gasoline in gallons, natural gas in cubic feet, and coal in tons or pounds.

Step 5: In column E, list the price per unit of the fuel displaced.

Step 6: For column F, multiply the figure in column E by the figure in column D and add the figure from column C.

Step 7: To compute the simple payback period (column G) divide the figure in column B by the figure in column F.

Step 8: To compute the payback period when considering an inflation rate, such as the current local inflation rate, use Table 2, and put the final figure in column H.

TABLE 1

A	B	C	D	E	F	G	H
NEW ITEM	($) COST INSTALLED (INVEST.)	($) DIFF. IN OP. & MAINT. COST (IF ANY)/YR	AMT. OF FOSSIL FUEL DISPLACED kwh, gal, or lbs.	($) COST PER UNIT	($) FIRST YEAR SAVINGS	(YRS) PAYBACK PERIOD, ZERO INFL.	(YRS) PAYBACK PERIOD, INC. INFL.
Solar Hot Water Heater	1,750	0.0	3995 kwh	0.06	239.70	7.3	5.7 (SAMPLE)

Table 2

Year	*Amount Saved Per Year*	*Total Paid Back Per Year*
1	$F_1 = F$	$T_1 = F_1$
2	$F_2 = F_1 \times (1 + I)$	$T_2 = T_1 + F_2$
3	$F_3 = F_2 \times (1 + I)$	$T_3 = T_2 + F_3$
"	" " " "	" " "
"	" " " "	" " "
n	$F_n = F_{n-1} \times (1 + I)$	$T_n = T_{n-1} + F_n$

To compute the payback period with the current local rate of inflation, use the first year savings found in column F of Table 1. For year one in Table 2, the figure from column F is the amount saved for the first year. For year two, F_1 is multiplied by 1 + I, where I is the local inflation rate. If, for instance, your inflation rate is 8%, then 1 + I is 1.08. If your current rate of inflation is 10%, the 1 + I is 1.10.

Using the example of the solar hot water heater shown in Table 1, what is the payback period with a local rate of inflation of 10%? There is no expected difference in operation and maintenance costs, therefore there is a zero in column C. Electricity is high in this area, costing $0.06/kwh. The first year savings is, therefore, 3995kwh x $0.06/kwh, or 239.70 as found in column F. The simple payback period is then B/F or 1750/239.70 = 7.3 years. The payback period with the 10% inflation is computed as follows, using the format in Table 2.

Year	*Amount Saved Per Year*	*Cumulative Payback (figured annually)*
1	$F_1 = 239.70$	$T_1 = 239.70$
2	$F_2 = 239.70 \times 1.1 = 263.67$	$T_2 = 239.70 + 263.67 = 503.37$
3	$F_3 = 263.67 \times 1.1 = 290.04$	$T_3 = 503.37 + 290.04 = 793.41$
4	$F_4 = 290.04 \times 1.1 = 319.04$	$T_4 = 793.41 + 319.04 = 1112.45$
5	$F_5 = 319.04 \times 1.1 = 350.94$	$T_5 = 1112.45 + 350.94 = 1463.39$
6	$F_6 = 350.94 \times 1.1 = 386.03$	$T_6 = 1463.39 = 386.03 = 1849.42$

Therefore, the payback period is between 5 and 6 years. To find out how much more than 5 years would be required, subtract the installed cost from the 6 year total, $1,849.40 - $1,750.00 = $99.40. Divide that figure by the 6th year cost, $99.40/$386.03 = 0.257, or 0.3. Now subtract the 0.3 from 6 and you get 5.7 years, or 5 years and 8.4 months.

GLOSSARY

GLOSSARY

ACID-FORMING BACTERIA - Bacteria which release organic acids as waste products of their metabolic activity.

ACTIVATED CHARCOAL - Highly absorptive carbon manufactured chiefly as a purifying agent.

ACTIVE SOLAR SYSTEM - A solar heating or cooling system that requires external mechanical power to move or regulate the collected heat.

ALDEHYDES - Any of a family of organic compounds characterized by the combination of carbon, hydrogen and oxygen.

ALGAE - Usually small but visible one or more celled photosynthetic plants that live in water or a very damp environment. Large salt water algae are called seaweeds.

ALGAE/SEWAGE SYSTEM - Sewage treatment system that uses algae which are simultaneously cultivated as an energy crop. The retention time and pond dimensions for this system differ from those necessary for simple algae sewage treatment.

ANNUAL PLANTS - Plants that do not live from one growing season to the next and must be regrown from seed each year.

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers.

AQUACULTURE - The culture of plants and animals in fresh water for human and animal foods.

BIOCONVERSION - Conversion of a form of energy not directly serviceable to man to one that will service his particular needs by living systems. Examples: processing of organic wastes into methane and other gasses by bacteria; storing solar energy in chemical form by "energy crops."

BIOFUELS - Fuels derived from living or recently living plant materials. Examples: wood, methane from sludge, alcohol from distillation.

BIOGAS - Gas generated by anaerobic digestion of organic wastes.

BIOMASS - Collective term that includes all plant material, from bacteria to trees, living or recently living.

BTU - British Thermal Unit, a measure of energy, equal to the amount of heat required to raise 1 lb. of water 1° F, at 50° F.

CATALYST - A substance (possible inert) that by chemical or physical action increases the rate of a chemical reaction without becoming part of the products.

CATALYTIC HYDROGENATION OF CO - Addition of hydrogen to carbon monoxide to yield methane (and water).

CELLULOSE - A relatively tough and rigid substance which constitutes the walls of plant cells.

CENTRIFUGAL COMPRESSOR - Compressor which takes in air at the center of a bladed impeller. Centrifugal force of blades revolving at high speed moves the air out toward the margin, where slowing action pressurizes the air.

CHAR - Charcoal, a black porous carbon prepared by burning plant or animal sources in the absence of oxygen.

CHEMICAL PRECIPITATION - Chemical precipitation of phosphates and nitrates constitutes the 3rd stage of sewage treatment. Substances are added to waste water which form insoluble compounds with phosphate and nitrate ions; the resulting precipitate falls to the bottom of the pond and the remaining fluid fraction can be filtered off.

CLONE - To grow multiple living individual organisms from a small sample of adult non-reproductive tissue rather than from germ cells.

COGENERATION - The use of waste energy from one energy-using process to drive another; the use of an energy-yielding process to power two or more energy-using subsystems.

COKE - Solid residue of coal left after destructive distillation, also used as fuel.

COMPRESSED AIR STORAGE - Use of surplus energy to run air compressor; compressed air is then stored in underground sealable caverns and released later to run low-pressure turbines or piston engines. Relatively low efficiency.

CREOSOTE - An oily brown or black liquid with a burning taste and penetrating odor, obtained by the distillation of wood tar.

DESTRUCTIVE DISTILLATION - Low-temperature pyrolysis of organic matter.

DIGESTER (methane) - Insulated, airtight container that mimics and hastens the natural anaerobic process of decay with the aid of bacteria. Makes possible the collection of concentrated combustible gasses as well as other useful products.

DISTILLATION - A process of evaporation and subsequent condensation of a liquid.

EFFICIENCY - Ratio of output to input (O/I) where output is the useful work performed and input is the energy used to operate the system. The higher the ratio, the more efficient the process under consideration.

ELECTROLYSIS - An electric current passing through a solution collects positive ions at the cathode, negative ions at the anode, which yield pure substances. Electrolysis of water yields hydrogen and oxygen gasses; electrolysis of hydrochloric acid yields hydrogen and chlorine, etc.

ELECTROSYNTHESIS - Reaction producing a new compound as a result of electric current passing through mixture of substances that would not otherwise react under the prevailing conditions.

ENERGY - The capacity for doing work. Different forms may be transformed from one type to another, such as thermal (heat), mechanical, electrical, chemical, graviational, radiant, nuclear.

ENTHALPY - Enthalpy is the sum of the internal energy of a system plus the system's volume multiplied by the pressure exerted on the system by its surroundings.

FEEDSTOCK - Biological resources which can be harvested for conversion to energy forms suitable for human use.

FLASH SEPARATION - Refers to technique for separating the different liquid products produced by pyrolysis; in this case, distillation, by rapidly reducing the pressure on the liquids.

FLUIDIZED BED - A body of finely crushed particles mixed with a gas and blown into a furnace so that the whole behaves as a turbulent liquid, thus promoting combustion or chemical reactions.

FLYWHEEL - A heavy wheel which moderates fluctuations of speed by its inertia.

FORMATES - Salts of formic acid.

GAS ENTRAINMENT - A process by which finely ground or chopped material is carried into a furnace, etc. by a moving stream of gas.

GASIFICATION - Conversion of certain solids, such as coal to gas.

GRID INTEGRATION - Connecting on-site generators and power-consuming systems with the local electric utility's system of generators, transformers, cables, etc. (called the electric grid) so that they function as if they were specialized parts of the grid.

HEADER - The pipe that gathers the heat transfer fluid in a collector. It maintains equal flow rates and pressure.

HEADRACE - The channel through which the headwater (water entering a turbine) flows from behind a damn or from a lake to the turbine.

HEAT EXCHANGER - A device, such as a coiled copper tube immersed in a tank of water, that transfers heat from one medium to another.

HECTARE - One hectare is 10,000 square meters or 2.471 acres.

HYDROCARBONS - Molecules composed of hydrogen and carbon only, in varying proportions. They are usually derived from formerly living materials and are readily burned to yield energy for human use.

HYDROELECTRIC ENERGY GENERATION - Production of electric power by a turbine generator turned by falling water.

HYDROGEN STORAGE - Surplus electric current is used to electrolyze water into its components, hydrogen and oxygen; the hydrogen is then burned as a simple fuel or stored in tanks for future use.

HYDROLYSIS - A method used to break down organic wastes into sugar, which can be converted to alcohol (ethanol). In the initial breakdown, either acids (acid hydrolysis) or enzymes (enzymatic hydrolysis) are used.

IMPULSE TURBINE - Composed of vertical wheels that use the kinetic energy of a jet of water to strike buckets or blades, turning the wheel.

INSOLATION - The total amount of solar energy that a surface receives.

INTEGRATION DEVICE - Equipment which allows locally produced (on-site) electricity to be connected to the utility grid.

INTERTIDAL - The part of the coastal region or seashore above the low tide mark.

INVERTERS - Device for converting direct current (DC) into alternating current (AC) by mechanical or electronic means.

KINETIC ENERGY - Energy associated with motion.

LAGOON - A large, usually shallow open pond in which sewage is treated by biological processes.

LIBERATION CUTTING - Cutting old, diseased or undesirable plants in an area of young growth in order to reduce competition and give the new plants freedom to develop.

LIGNIN - An amorphous substance related to cellulose that with cellulose forms the woody cell walls of plants and the cementing substance between them.

MARICULTURE - Cultivation of marine (salt-water) species of plants and animals for human use.

MARSH GAS - Methane, CH_4, generated by spontaneous anaerobic digestion of decaying organic matter in swamps. It rises to the surface of swamp water and sometimes ignites, causing "will-o-the-wisps."

METHANE - A highly combustible gas, CH_4. Colorless, odorless, and tasteless. Stove gas.

METHANOGENS - Bacteria that release methane as a waste product of its metabolic activity.

METHANOL - Wood alcohol, CH_3OH. A combustible fuel.

MOLE (Biomass) - Molecular weight: gram molecule.

MULCH - Any lightweight, friable, relatively inert substance, such as paper, small wood chips, or hay, that can be spread over the soil around plant stems to prevent evaporation, inhibit weed growth, and obstruct pests.

NAPTHA - Mixture of volatile, often flammable hydrocarbons used chiefly as solvent.

NO_x or SO_x - Different combinations of oxygen atoms with either nitrogen or sulfur atoms. X = 2, 3, etc. Could be toxic.

NUTRIENT BALANCE - A set of nutrients in the right proportion for a given organism is said to be in balance.

ORGANIC MOLECULE - A molecule containing carbon compounds, relating to or derived from living organisms. The chemical behavior of organic compounds is generally distinct from that of inorganic compounds, substances that do not exhibit carbon bonding.

PASSIVE SOLAR TECHNOLOGY - The technical knowledge of how to design solar heating or cooling systems using no external mechanical power to move the collected solar heat. Passive systems are chiefly a matter of architecture; orientation and spatial relations of building parts.

PAYBACK - Benefits returned by a newly-installed system. Simple payback is calculated by dividing the initial investment by the first year's expected savings.

PEAK POWER REQUIREMENT - The maximum demand that a power generating system may need to fill at any one time. When all of the possible appliances/machines connected to the system are on and operating under maximum load.

PENSTOCK - A conduit or pipe through which water flows to a turbine.

p^H - The negative logarithm of the effective hydrogen-ion concentration or hydrogen -ion activity in gram equivalents per liter used in expressing both acidity and alkalinity on a scale of 0 to 14. Seven (7) represents neutrality, numbers less than 7 increasing acidity, and numbers greater than 7 increasing alkalinity.

PHOTOSYNTHESIS - The synthesis or building of glucose from carbon dioxide and water by specialized structures and substances in the cells of green plants.

PHOTOVOLTAIC CELL - Semi-conductor devices that convert solar energy to electricity.

POTENTIAL ENERGY - The energy that a piece of matter has due to its position or because of the arrangement of parts.

PUMPED WATER STORAGE - Surplus energy generated by wind, bioconversion, etc. is used to pump water to a higher level where it is stored (usually behind a dam), as potential energy.

PUMP STORAGE - Using surplus energy to run a pump which then moves some gas or liquid into a place where it will have considerable potential energy due to either its pressure or its elevation.

PYROLYSIS - Chemical change brought about through the action of heat.

REACTION TURBINE - Reaction turbines run submerged, with a draft tube and a continuous column of water from head race to tail race.

RECYCLE - To convert material usually designated as waste into a useful product, thus beginning a new cycle for human use.

REGENERATIVE PRODUCTION - A method of production that yields not only a product to be consumed but a new supply of the original materials and a new beginning of the original process.

RENEWABLE ENERGY TECHNOLOGY - The application of scientific knowledge to the use of energy sources that are unlikely to be exhausted in the near future, such as, solar radiation, photosynthesis and its products and by-products, wind, waves, tides, falling water, and geothermal heat.

RESISTANCE HEATING ELEMENT - A wire or group of wires that resist the passage of electric current thereby generating heat.

RETROFIT - The modification of a system to affect favorable energy consumption characteristics.

REVERSION COMPOUNDS - The chemical compounds used to produce a chemical reaction will revert to their original form if the proportion of reactants to products is not kept sufficiently high. A reversion compound can be produced when the desired reaction stops and the reaction process runs backwards.

SECONDARY CELL - Cell that can be recharged by reversing chemical action with electric current.

SEMICONDUCTOR - One of a class of solids whose electrical conductivity is between that of a conductor and that of an insulator, since its conductivity is nearly metallic at high temperatures and nearly absent at low temperatures.

SHIFT CONVERTER - In the conversion of coal to methane, a chamber where the ratio of hydrogen to carbon monoxide is altered to 3:1 using a catalyst.

SILAGE - Fodder converted into succulent feed for livestock through anaerobic acid fermentation.

SILICON - A tetravalent nonmetallic element that occurs combined as the second most abundant element in the earth's crust. It's a semiconductor.

SILVICULTURE - Cultivation of woodlands and forests for human use.

SLUDGE - Precipitated solid matter resulting from water sewage treatment processes. The solid portion of sewage.

SLUICE GATE - An artificial passage for water fitted with a gate for stopping or regulating flow.

SLURRY - A mixture of water and organic wastes, the raw material initially fed into a methane digester.

SMACNA - Sheet Metal and Air Conditioning Contractors National Association.

SOLAR ELECTRIC - Process by which solar radiation is converted directly to electricity (See Photovoltaics.)

SOLAR THERMAL - Process by which the sun's radiation is converted into heat.

SORGHUM - A grain-yielding plant cultivated for its sugar content.

STABILIZATION POND - A large open holding pond in which bacteria grow, using nutrients in the water for their own vital processes, reducing nitrates and phosphates from sewage.

STACK EMISSIONS - Waste gasses discharged into the atmosphere through smokestacks.

SWITCHING CIRCUIT - Any circuit which can be used to disconnect (or temporarily connect) power.

SYNGAS - Synthetic gas. Yields less energy than equivalent volume of natural gas, but can be further processed for higher yield.

TAIL RACE - The channel through which the tailwater (water that has passed through a turbine) is removed from the turbine.

TAR - Mixture of various hydrocarbon compounds, the by-product of destructive distillation.

TERTIARY WASTE (SEWAGE) TREATMENT - The third stage of sewage treatment process. Phosphates and nitrates are largely removed from water by precipitation, or, more recently, by stabilization pond algae.

THERMAL DECOMPOSITION - Breakdown of larger compounds into smaller ones through the disruptive action of heat.

THYRISTOR - One of a family of semi-conductor devices having turn-on characteristics that can be externally controlled by either current or voltage.

TONNE - The English spelling for ton, the English ton is 2,240 lbs. versus the U.S. ton of 2,000 lbs.

UPWELLING - The flowing upwards of warmer waters from a spring or well in the floor of a body of water.

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